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Effects of Personal FM System Use During Phonological Awareness Instruction for Children at Risk for Dyslexia

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EFFECTS OF PERSONAL FM SYSTEM USE DURING PHONOLOGICAL AWARENESS INSTRUCTION FOR CHILDREN AT RISK FOR DYSLEXIA

by

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ABSTRACT

Students with reading impairments, including dyslexia, account for the largest proportion of students receiving special education services in the United States (NCES, 2016). Developmental dyslexia is characterized by slow and inaccurate word decoding (Lyon et al., 2003). This word decoding difficulty results from deficits in phonological awareness, a sound-based skill (Swan & Goswami, 1997). Classrooms are known to have high levels of background noise and are inconsistent with recommendations for optimal listening (Picard & Bradley, 2001) or accepted standards (ASHA, n.d.). Furthermore, degraded acoustic conditions have been related to poorer performance on speech-recognition tasks even for children with normal hearing (Finitzo-Hieber & Tillman, 1978; Nabelek & Pickett, 1974) and the impact of classroom noise on academic performance may be greater for children with special educational needs (Shield & Dockrell, 2008).

FM systems are devices that enhance the signal-to-noise ratio in noisy environments with high amounts of background noise, such as classrooms, and allow the listener clear access to the teacher’s voice without also amplifying background noise. A limited amount of existing research on the use of FM systems for children with normal hearing suggests that use of amplification technology is associated with academic and social advantages. Provision of FM systems to students with dyslexia results in increased teacher rating and objective measurement of reading skills in a classroom setting (Hornickel et al., 2012; Purdy

et al., 2009), but the specific effects of FM system use on phonological awareness skills has not been evaluated.

This study investigated the benefit of an FM system during phonological awareness intervention in two studies. Study 1 evaluated the effects of utilizing an FM system during phonological awareness intervention for students at risk for dyslexia with phonological awareness weaknesses in a classroom setting. Study 2 investigated the acquisition of phonological awareness skills targeted during a virtual intervention with simulated classroom noise compared to a condition with a simulated benefit of a classroom-based FM system.

In Study 1, four participants received in-person phonological awareness intervention in small groups during the school day. They were assigned to wear an FM system during lessons targeting one skill; during lessons targeting the other skills they received the intervention alone. In Study 2, three participants completed one-on-one phonological awareness intervention through Zoom. They were assigned to learn one skill with simulated classroom noise and another with the simulated benefit of a classroom FM system. Both studies utilized adapted alternating treatment single-case designs and assessed performance using daily assessments on the phonological awareness skills targeted during intervention and one additional phonological awareness skill.

In Study 1, two participants demonstrated quicker and more pronounced improvement on the skill learned while wearing the FM system, suggesting FM systems show promise as a tool to use during phonological awareness training. In Study 2, two participants made gains on the phonological awareness skills assessed. However, a difference was not evident between skills learned in the simulated classroom FM and simulated classroom noise condition.

The results of Study 1 indicate that FM systems show promise during phonological awareness instruction. However, the finding from Study 2 that simulation of the signal-to-ratio of FM systems was not associated with improved performance compared to simulated classroom noise suggests that aspects of FM systems beyond the increased signal-to-noise ratio alone may be responsible for the benefit they provided. Additionally, findings from Study 2 indicate that virtual phonological awareness instruction holds promise as a method of delivery.

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CHAPTER 1

INTRODUCTION

Dyslexia

Reading impairment, including dyslexia, comprises the largest proportion of students receiving special education services in the United States (NCES, 2016). Historically, the prevalence of dyslexia has been estimated to be 15% to 20% of the US population (Coles, 1998; Shaywitz & Shaywitz, 2005). However, recent research has concluded that the prevalence may vary based on operational definitions and cut points of performance (Fletcher et al., 2019; Wagner et al. 2020). Dyslexia is neurobiological-based disorder defined in a seminal work by Lyon and colleagues (2003) as a learning disability characterized by difficulties with word recognition, spelling, and decoding resulting largely from deficits in phonological awareness.

The primary impairment in dyslexia is impaired word-level reading (Alt et al., 2017; Catts et al., 2006; Gough & Tunmer, 1986; Melby-Lervåg et al., 2012; Stanovich, 1982; Vellutino, 1979; Vellutino et al., 2004). Difficulties with sound-to-letter correspondence are largely responsible for difficulties with word-level decoding (Bruck, 1992; Hulme et al., 2012; Rack et al., 1992; Vellutino et al., 2004). Sound-to-letter correspondence difficulties are due to weaknesses in phonological awareness (Bruck, 1992; 1993; Hulme et al., 2002; Melby-Lervåg et al., 2012; Stanovich, 1988; Ramus & Szenkovits, 2010). Children with dyslexia struggle to rapidly and easily access phonological information when decoding text (Gough & Tunmer, 1986; Ramus & Szenkovits, 2010; Zoccolotti et al., 2014).

Phonological-Based Impairment

Historically, some researchers have contended that the etiology of dyslexia is attributed to visual-attentional deficits, such as in the magnocellular theory (Stein & Walsh, 1997), while others argued for language-based deficits (Kamhi & Catts, 1986), phonological deficits (Vellutino et al., 2004), or even processing of speech sounds (Goswami et al., 2002). Recently, it has become more widely accepted that the deficits of individuals with dyslexia stem from phonological processing. Specifically, it is believed the word-reading difficulties encountered by individuals with dyslexia stem from deficits in the phonological domain (Ramus, 2001; Stanovich, 1988; Stanovich & Siegel, 1994; Vellutino et al., 2004). This theory is referred to as the phonological deficit hypothesis. The phonological deficit hypothesis suggests that deficits relating to phonological representations of speech sounds cause difficulty mapping phonemes onto letters and ultimately impact word-level decoding and literacy skills (Snowling 1998; Vellutino, 1996).

However, disagreement still remains surrounding the specific deficits related to phonological representations. In children with typical development, research suggests children are first able to map larger segments of acoustic information onto articulatory movements; this pairing gradually becomes more specified until the sound matches the articulatory gesture at the phoneme level (Snowling & Hulme, 1994). Conversely, phonological representations in individuals with dyslexia have been described in several ways, including “fuzzy” (Claessen et al., 2009), “weak”, or “underspecified” (Boada & Pennington, 2006; Fowler, 1991). A study by Metsala (1997) found that children with dyslexia required more speech input to complete a word recognition task using a lexical gating paradigm, where a word is presented in successive fragments and participants guess the target word. A more recent study by Boada and Pennington (2006) investigated implicit phonological representations in children with dyslexia and typical development using three tasks: lexical gating, priming, the first part of a word is played and participants guess the target word, and syllable similarity, participants are taught made up single-syllable words for animals and confusion errors are analyzed. They concluded that children with dyslexia have poor phonological representations that are less mature than their peers with typical development.

Furthermore, some researchers argue that the difficulty does not lie within the formation of representations but rather with the access to these representations (Ramus & Szenkovits, 2008; Ramus, 2014). Specifically, Ramus (2014) contends that the finding of normal activation of superior temporal regions for speech in individuals with dyslexia compared to a control group in a neuroimaging study by Boets and colleagues (2013) supports the hypothesis of intact phonological awareness representations but impaired retrieval of these representations for individuals with dyslexia. It is difficult to tease apart the development and retrieval of phonological awareness representations and study them in isolation, therefore the precise role played by phonological representations in the development of literacy skills for individuals with dyslexia is fuel for continued research.

Nonetheless, the phonological deficit hypothesis is the leading causal theory of the etiology of dyslexia. Within this broad hypothesis, several research groups have differing theories of the basis of the phonological deficits. Goswami and colleagues posit that a widespread auditory deficit motivates other areas of difficulty for individuals with dyslexia. This theory is referred to as the temporal sampling theory. They argue that the perception of auditory signals, specifically those responsible for conveying information related to rhythm, tempo, and stress, is impaired in individuals with dyslexia. In turn, this auditory deficit limits the ability to utilize prosodic cues when learning early literacy and phonological awareness skills (Goswami et al. 2002; Goswami et al., 2013; Goswami, 2015). The deficits related to processing prosodic auditory information cause subsequent difficulties with phonological skills.

Another research group, Ziegler and colleagues, argue that the impairments stem from a general temporal processing deficit. Specifically, they contend that deficits related to temporal processing, processing stimuli over time, are present in auditory and non-auditory domains, with speech and non-speech stimuli. Ziegler and colleagues (2005) found that individuals with dyslexia have difficulty with speech-in-noise perception which may be related to their decoding deficits (Ziegler et al., 2005; 2009). More recently, this research group has found deficits in temporal processing for individuals with dyslexia in auditory and visual domains that led to phonological deficits (Casini et al., 2017).

Other researchers have investigated the auditory skills of individuals with reading impairment. A study by White-Schwoch and colleagues (2015) investigated the speech-in-noise perception of preschool children. They found that children with difficulties with speech-in-noise perception and phonology were at greater risk for lower preliteracy skills one-year later compared to their peers without this difficulty. They conclude that difficulty processing speech-in-noise may contribute to literacy deficits.

Additionally, Werfel and colleagues found that hearing related difficulties may be a potential contributing factor to poor reading outcomes in students with reading impairment (Werfel & Hendricks, 2016; Werfel et al., 2020). Werfel et al. (2020) found that 54% of school-age children with reading impairment failed a hearing screening compared to only 21% of school-age children with typical reading skills, consistent with prior research (Carroll & Breadmore, 2018). Thus, a large proportion of students with dyslexia exhibit hearing related difficulties and may overlap with those students who are nonresponsive to current best-practice literacy instruction. Furthermore, degraded classroom listening conditions adversely affect children with normal hearing, especially those with special education needs (Shield & Dockrell, 2008). If children with reading impairments, the greatest proportion of US students receiving special education services, are at greater risk for hearing related difficulties, a classroom listening unconducive to academic success would have even more deleterious effects.

Phonological Awareness

Phonological awareness is the ability to think about and analyze sounds in words independent from meaning (Mattingly, 1972; Wagner & Torgesen, 1987). Specifically, phonological awareness refers to the ability to recognize, discriminate, and manipulate the sounds in a language (Anthony & Francis, 2005). Phonological awareness is a foundational literacy skill that underlies word decoding for children with and without reading impairment (Adams, 1990). Phonological awareness plays an important role in development of early literacy skills. Phonological awareness in preschool and kindergarten children with typical development is related to later literacy achievement (Calfee et al., 1973; Catts et al., 2001; Hogan et al., 2005; Kirby et al., 2003; Lonigan et al., 2000; Powell & Atkinson, 2020; Torgesen et al., 1994; Wagner et al., 1997).

Acquisition of phonological awareness skills in children with typical development follows a developmental trajectory. Children typically acquire phonological awareness skills in the preschool and early elementary years (Anthony et al., 2003; Anthony & Francis, 2005). As they develop phonological awareness skills, children become increasingly able to analyze smaller parts of words (Treiman & Zukowski, 1991). That is, they are able to analyze parts of words or syllables before they are able to analyze individual sounds. Anthony and colleagues (2003) further suggest that children are first able to detect if words sound the same or different (rhyme) before they can manipulate sounds in words. Additionally, children are continuously refining their phonological awareness skills as they learn new ones; mastery of one skill is not necessary for acquisition of the next. By first grade, children are typically able to segment, isolate, and delete phonemes in words (Anthony et al., 2003).

Phonological Awareness in Children with Reading Impairment

Phonological awareness weaknesses are directly linked to impairments in word-level decoding (Bruck, 1992; Catts et al., 2001; Hogan et al., 2005; Kirby et al., 2003; Lonigan et al., 2000; Powell & Atkinson, 2020; Ramus & Szenkovits, 2010; Stanovich, 1988). Children with decoding-based reading impairments exhibit difficulty with phonological awareness (e.g., Catts et al. 2005), and conversely, children with phonological awareness deficits are at risk for developing dyslexia (Elbro & Peterson, 2004; Stanovich, 1986). Phonological awareness is a primary weakness for individuals with dyslexia and causes subsequent difficulties in word-level decoding and spelling. In fact, seventy-five percent of studies in a meta-analysis conducted by the National Reading Panel (2000) utilized weaknesses in a phoneme awareness task to determine risk of developing dyslexia. Although it is a primary deficit for individuals with dyslexia, evidence comparing individuals with dyslexia to younger reading-age matched controls show that individuals with dyslexia make some growth related to phonological processing (De Gelder & Vroomen, 1991), suggesting proficiency is not unattainable.

Phonological Awareness Intervention

A meta-analysis conducted by the National Reading Panel (NRP) found phonological awareness instruction effective for improving reading outcomes for children with existing reading impairments (2000). In wake of the report from the National Reading Panel (2000), additional studies and multiple meta-analyses have further investigated the effectiveness of phonological awareness intervention (Al Otaiba et al., 2009; Ehri et al., 2001; Suggate, 2010). These studies have supported the NRP finding that phonological awareness intervention improves reading skills for children with typical development and children at risk for reading impairment (Al Otaiba et al., 2009, Ehri et al., 2001; Suggate, 2010; Thompson et al., 2015).

Even though phonological awareness instruction is effective overall for improving reading skills in kindergarten and first graders, not all students' skills increase as a result of instruction. Approximately 20% to 30% of children at risk for reading impairment do not adequately respond to high quality sound-based intervention (Al Otaiba & Fuchs, 2002; Torgesen, 2000). Even for students receiving explicit evidence-based phonological awareness intervention in kindergarten and first grade, over one third failed to perform within or above the normal range on reading at the end of each year (Al Otaiba & Fuchs, 2006). There remains a substantial percentage of students for whom best-practice intervention is ineffective, despite relatively early identification of reading difficulties and timeliness of intervention.

Tenets of effective phonological awareness intervention. A study conducted by Williams (1980) utilized several recommended aspects of a successful training program. Williams investigated the use of *The ABD's of Reading* program, which explicitly taught phoneme blending and linked sounds to letters. Lessons in this program followed a specified sequence and utilized a limited set of consonants and vowels. This program was used in the classroom setting for children with learning disabilities aged seven to twelve over 26 weeks. The students in this program demonstrated improved ability to decode words compared to their peers who did not complete this program. Blachman and colleagues (1994) investigated the use of phonological awareness intervention in at-risk kindergarten children. Students in the intervention condition participated in 15- to 20-minute phonological awareness lessons four times a week over 11 weeks in small groups. After participating in the intervention, the students performed better than their peers in the control group on measures of phonological awareness, letter naming, letter-sound knowledge, and word reading.

Overall, the NRP made several conclusions about phonological awareness intervention. First, most successful phonological awareness intervention lasts 5 to 18 hours in total. The average length of sessions was 25 minutes, with most of the sessions not lasting beyond 30 minutes. Secondly, the intervention should include blending and segmenting tasks. Next, the intervention should be explicit. Lastly, most effective intervention was found to occur in small groups of two to seven students. The NRP posited the higher effectiveness of small groups may be due to the opportunity to listen to the comments and feedback from peers or the motivating factor of performing in front of peers.

Classroom Acoustics

Standards of Classroom Acoustics

Classrooms have high levels of background noise that are not consistent with recommendations for optimal listening (Picard & Bradley, 2001). The American National Standards Institute (ANSI) and the American Speech-Language Hearing Association (ASHA) jointly created recommendations for classroom acoustics for school-aged children with normal hearing and typical development, including noise levels and reverberation time (ANSI, 2010; ASHA n.d.). Reverberation occurs when sound is reflected back off surfaces in a room. The reverberation time is how quickly sound dies down in a room; the measurement RT60 refers to how long in seconds it takes for a sound of 60 dB to completely decay (ASHA, n.d.). These standards recommend a maximum unoccupied classroom noise level of 35 dB and a maximum reverberation time (RT60) of 0.6 seconds (ANSI, 2010). An investigation by Spratford and colleagues (2019) of unoccupied classrooms found that the classrooms met the recommendations for reverberation time. However, fewer than 15% of unoccupied classrooms met the recommended noise levels (Spratford et al., 2019). Likewise, Gremp and Easterbrooks (2018) reported that no classroom they measured met the noise level guidelines for unoccupied classrooms, including classrooms specifically designated for specialized instruction for children with hearing loss.

Degraded Listening Conditions and Academic Performance

Degraded acoustic conditions in classrooms are a significant barrier to academic success for students in primary through high school. Reviews on the effects of noise on school age children have identified multiple areas necessary for educational achievement that are negatively impacted by exposure to noise, including impaired auditory discrimination, attention, and speech intelligibility (Berglund & Lindvall, 1995; Evans & Lepore, 1993; Hétu et al. 1990; Shield & Dockrell, 2003). For over forty years, noise in the classroom has been documented at too high levels incompatible with teacher and student well-being and performance (Evans & Lepore, 1993; Hétu et al. 1990; Ko, 1979; 1981; Sargent, 1980; Shield & Dockrell, 2008). Furthermore, degraded acoustic conditions have been related to poorer performance on speech-recognition tasks for children with and without hearing loss (Finitzo-Hieber & Tillman, 1978; Nabelek & Pickett, 1974). Despite this early attention, classroom acoustics have not made significant improvements over the past several decades and fall drastically short of meeting the recommended guidelines (ASHA, n.d.; Crandell & Smaldino, 2000; Picard & Bradley, 2001; Spratford et al., 2019).

A few studies have investigated the role classroom noise plays on literacy skills. Hétu et al. (1990) identified a correlation between noise exposure and delays in reading performance for elementary school children. A study by Maxwell and Evans (2000) specifically investigated the pre-literacy skills of preschool children before and after their classroom was acoustically treated to attenuate sound. In the quieter classroom, the children scored higher on measures of letter, number, and word recognition; their language skills were rated higher by their teachers and they worked longer on an unsolvable puzzle compared to students in the louder classroom. Lundquist and colleagues (2000) measured the sound level in classrooms while students were working on a mathematics lesson. They found that the noise level in the classrooms ranged from 58 to 69 dB and noise was associated with ratings of annoyance from the students and teachers. More recently, Shield and Dockrell (2008) investigated the impact of external and internal noise on academic performance. They found that external and internal classroom noise had a negative impact on the reading and spelling skills of eight-year-old school children. Furthermore, they concluded that children with special educational needs were more adversely affected by internal classroom noise, such as classroom babble. Classroom noise has a negative impact on academic attainment for children with typical development and the impact of classroom noise appears to be greater for children with specialized education needs.

FM Systems

A personal FM (Frequency Modulation) system is one approach to adjust the signal-to-noise ratio to be more conducive to student success. Signal-to-noise ratio refers to the ratio of the desired signal, such as teacher's voice, to the level of background noise. FM systems are devices that increase the signal-to-noise ratio in environments with high amounts of background noise, such as in a classroom. The components of a personal FM system include a transmitter microphone worn by the speaker, such as the teacher, around the neck or attached to a lapel collar clip. The students wear behind-the-ear receivers on both ears that also allow them access to environmental noise. The receivers transmit the sound from the microphone worn by the teacher. Unlike hearing aids, the speaker's voice is amplified while the classroom background noise is not. This technology allows for amplified transmission of the teacher's voice without also amplifying background noise or reverberation. FM systems can be used by individuals with hearing loss, in conjunction with hearing aids or cochlear implants, to increase speech recognition in noise (Schafer & Thibodeau, 2006) or by individuals with normal hearing. By increasing the signal-to-noise ratio, FM systems may mitigate the negative effects of classroom background noise during reading instruction.

Classroom Studies with FM Systems for Children with Normal Hearing

Existing research on the use of FM technology for children with normal hearing suggests their use in the classroom is beneficial. In particular, the use of FM systems for children with autism spectrum disorder (ASD) has been the focus of a significant number of studies investigating assistive hearing technologies in classrooms; other populations investigated include children with auditory processing disorder or attention deficit hyperactivity disorder (ADHD). The use of FM systems in these populations was associated with increased teacher rating of listening behaviors and school performance. The research on the use of FM systems for children with reading impairments is even more limited.

Children with ASD. In an initial investigation, Schafer and colleagues (2013) investigated the use of FM systems for children with ASD and/or ADHD in a preliminary study of 11 children, the first time the use of this technology was assessed with either population. The participants wore the FM systems for a total of 5 weeks, 45 minutes per school day during teacher-led reading and math period. The authors found improved teacher rating of listening behaviors, increased on-task behaviors, and better speech recognition in noise for children with ASD and/or ADHD, suggesting a promising beginning to this research area. In a follow-up study, Schafer et al. (2016) explored the use of FM systems in children with ASD in the classroom for six weeks and found student-reported improvement on a measure of educational listening (Listening Inventory for Education-Revised (L.I.F.E.-R.; Anderson et al. 2012) from pre to post test. Rance and colleagues (2014) further explored the use of FM systems for 20 students with ASD in a 6-

week trial with the devices worn up to seven hours per day. The authors reported increased ease of interaction in the classroom for students with ASD when using FM systems. A systematic review of five studies on improving signal-to-noise ratio for students with ASD by van der Kruk et al. (2017) concluded that research suggests improving the signal-to-noise ratio through use of personal FM systems improves classroom listening behaviors for students with ASD.

Children with ADHD and APD. Johnston and colleagues (2009) investigated the use of FM systems in several domains for school-aged children with auditory processing disorder. They found the use of FM systems during the school day for a period of five or more months was associated with greater speech perception, as well as academic and social benefits. Friederichs and Friederichs (2005) concluded FM use in the classroom was associated with improved performance on auditory function tasks, and ratings of improved school performance by parents and teachers for children with ADHD and suspected central auditory processing disorder. The emerging research on the use of assistive technology with these clinical populations suggests that they have utility for a range of needs beyond individuals with hearing loss.

Children with Dyslexia. Some studies have explored the use of FM systems in the classroom for students with dyslexia to improve academic performance. Blake et al. (1991) investigated the use of FM systems for children with learning disabilities at a specialized school and found they were associated with improved attention in the classroom. In 2009, Purdy and colleagues investigated the effects of a six-week FM trial for 6–11-year-old children with a reading delay. Wearing the FM systems throughout the school day for that period resulted in increased teacher rating of classroom listening. A study by Hornickel and colleagues (2012) evaluated the use of FM systems in a group of students from a private school for children with severe reading impairment. The participants wore FM systems for an entire school year during the full school day. These children showed increased performance on standardized measures of reading and phonological awareness, although phonological awareness skills were not directly targeted. The findings from Hornickel and colleagues suggest that assistive listening devices can impact literacy skill development for individuals with reading difficulties.

There is a limited amount of research on the use of FM systems for children with typical hearing. However, very few studies have investigated the use of FMs for students with reading impairment and even fewer have investigated the use of FM systems during literacy instruction in particular. No study to date has explored the use of FM systems during phonological awareness instruction for students with reading impairment. The existing research suggests that use of amplification technology is associated with academic and social advantages. However, additional research is needed to determine 1) specifically what skill areas are associated with growth resulting from FM technology and 2) how long FM systems must be in use to obtain maximum benefit.

Telepractice

Telepractice is defined by ASHA as the use of telecommunication technology to provide speech language pathology or audiology services from a clinician to a client for assessment, intervention, or consultation (ASHA, 2019b). Telepractice has been in use for decades, with documented use as early as 1999 (Short et al., 2016). However, given COVID-19 related school closures and restrictions on service delivery, a record number of clinicians are now conducting telepractice sessions. Researchers as well have adapted their study designs to entirely online formats (Werfel et al., in press).

Efficacy of Telepractice

Existing research suggests telepractice is associated with progress similar to in-person therapy (Coufal et al., 2018; Fairweather et al., 2016; Short et al., 2016). Even for activities requiring fine-tuned auditory analysis, such as speech sound disorder, preliminary evidence suggests teletherapy may be an efficient delivery method of intervention (Coufal et al, 2018; Jessiman, 2003; Lee, 2018; Pullins & Grogan-Johnson, 2017). Jessiman (2003) found telehealth to be a viable method of conducting speech-language therapy for a variety of goals, including those targeting articulation and phonological delays. In 2016, Fairweather and colleagues investigated the use of teletherapy in rural education settings targeting goals that included phonological awareness skills. Teletherapy was found to result in similar outcomes to in-person therapy. Relatedly, Lee (2018) concluded that teletherapy was successful for targeting phonological disorders, which require fine-tuned auditory analysis similar to targeting phonological awareness skills. Furthermore, Cohn and Cason (2012) concluded that teletherapy is a viable option to provide both speech-language and audiological services to individuals with hearing loss.

Telepractice for Phonological Awareness Skills

Only a few studies have specifically examined the use of teletherapy to address phonological awareness skills. Waite and colleagues (2010) successfully assessed children's literacy skills, including phonological awareness, using telepractice. This finding has been supported more recently by Werfel and colleagues (in press). Lastly, a feasibility study by Lee and colleagues (2017) compared phonological awareness intervention delivered via telepractice to in-person delivery for children with hearing loss. This study found improved phonological awareness skills in both groups and no significant differences between groups, suggesting the viability of teletherapy for phonological awareness intervention, even in children with impaired hearing abilities.

In sum, several studies have demonstrated the viability of telepractice for activities requiring auditory analysis of small parts of words, including therapy targeting articulation, phonological processes, and phonological awareness. Additionally, researchers have endorsed the use of teletherapy in populations with reduced hearing abilities, individuals with hearing loss. A study by Lee and colleagues furthermore found phonological awareness conducted via therapy to have similar results compared to in-person delivery. Therefore, it is hypothesized that students who receive phonological awareness treatment via teletherapy will make similar progress to those who receive the intervention in person. The research on virtual phonological awareness intervention is limited and this study will address this gap in research.

Future of Telepractice

It is likely that telepractice will remain a mainstay of the profession even as COVID-19 related restrictions are lifted in the coming months or years. Telepractice now has its very own ASHA Special Interest Group (www.asha.org/sig). Therefore, investigation into the transferability and replicability of existing efficacious interventions and skill attainment from virtual instruction is warranted.

Rationale for Study 1

Individuals with dyslexia have impairments related to the phonological representations of speech sounds that impact their ability to develop phonological awareness skills. Provision of FM systems to these children at risk for dyslexia during phonological awareness training may remedy this breakdown of information processing. Given the documented auditory difficulties of children with dyslexia, these individuals may benefit from increased signal-to-noise ratio in school, particularly during literacy instruction. Previous studies have found positive effects of FM systems in classroom listening (Purdy et al., 2009) and reading outcomes (Hornickel et al., 2012) for children with dyslexia. However, FM system use during phonological awareness intervention has not been evaluated. This study examined the effects of utilizing an FM system during a phonological awareness training, the Intensive Phonological Awareness program (IPAP; Scheule & Murphy), for students with phonological awareness weaknesses.

Rationale for Study 2

The second iteration of this study investigated the use of a 6-week adaptation of an evidence-based phonological awareness program, the IPAP (Schuele & Murphy, 2014) in a virtual setting. Recruitment and participation occurred virtually. Participation in the intervention occurred one-on-one instead of in small groups.

Given known difficulties encountered when listening in degraded acoustic conditions, such as in a classroom, the role of adverse listening conditions and background noise may be a contributing factor to the limited success of evidence-based interventions in the school setting. Therefore, it is essential to further investigate the potential role of background noise and auditory environment on reading instruction and specifically intervention involving fine-tuned analysis of small units of speech. The auditory benefit of an FM system was explored through simulated classroom background noise and simulated FM-provided auditory benefit. This study investigated both the replicability of the intervention program used in Study 1 and the use of simulated background noise to approximate the classroom learning environment.

Research Questions

Study 1 Research Question: Is there an additive effect of an FM system during phonological awareness training on phonological awareness skills in children at risk for dyslexia?

Study 2 Research Questions: 1) Does phonological awareness intervention delivered via teletherapy lead to improvement in phonological awareness skills in children at risk for dyslexia? 2) Is there an additive effect of a simulated classroom FM system during phonological awareness training on phonological awareness skills compared to skills learned during a training with simulated classroom noise?

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CHAPTER 2

METHOD

All study procedures were approved by the University of South Carolina Institutional Review Board.

Experimental Design

A single-case research design, specifically adapted alternating treatment design, that met all the What Works Clearinghouse guidelines for single-case designs without reservation (Kratochwill et. al., 2010) was utilized for both studies. An adapted alternating treatment design begins with a baseline period, as typical in other single-case designs, followed by an experimental condition during which two or more interventions are alternated (Sindelar et al., 1985). By using an adapted alternating treatment design, two or more instructional approaches can be compared within one participant. Additionally, the progress monitoring used in single case designs allow for detailed tracking of skill acquisition. This design allows for comparison of participants' response to two different interventions across multiple time points per week. Therefore, this design was utilized in order to compare the additive effects of phonological awareness training + an FM system beyond phonological awareness training alone.

Extraneous variables unrelated to the intervention were controlled. Specifically, both lessons, segmenting and isolation, occurred at the same time of day, one directly after the other. Additionally, the order of the presentation of the lessons was alternated each day. All intervention sessions occurred in the same classroom with the same teacher and same group of students. Extraneous classroom members, such as additional staff or visiting students, were not present during the intervention.

Other single-case research designs were considered but were ruled out due to incompatibility with the delivery of the intervention within a small group or reversibility of learned skills. One such design is a multiple-baseline design. In a multiple-baseline design, the introduction of the independent variable is staggered across different points in time (Kratochwill et al., 2010). Prior to the introduction of the independent variable, the dependent variables or participants remain in the baseline phase. During this phase, there is no independent variable and no change is expected. A multiple baseline design can occur within one participant, with multiple targets assessed and targeted at different time points, or across participants, with a participant entering the intervention phase only when the previous participant has responded to the intervention. In this design, the entry of the participants into the intervention phase is staggered Therefore, it would not be compatible with use in a school-based intervention occurring in small groups.

Another experimental design considered was an ABAB design, also called a reversal or withdrawal design. This single-case design requires that the intervention be repeatedly introduced and withdrawn (Kratochwill et al., 2010). Although an ABAB design allows for clear demonstration of experimental control by introducing and removing an intervention, it is only able to be used for behaviors that are reversible. It is not an appropriate method to evaluate an intervention addressing behaviors that are not expected to be reversed, such as learning a new skill (Kratochwill et al., 2010). Therefore, since the goal of the intervention was for participants to develop phonological awareness skills that would not revert to pre-intervention levels, a reversal design is not an appropriate paradigm.

Study 1

Study 1 sought to explore the use of FM systems during phonological awareness intervention for children at risk of dyslexia with phonological awareness weaknesses. Individuals with dyslexia struggle to develop phonological awareness skills due impairments relating to representations of speech sounds. Furthermore, classrooms have high amounts of background noise and the academic performance of children with special educational needs are particularly impacted by this noise (Shield & Dockrell, 2008). Previous research has found positive effects of FM systems in classroom listening for children with dyslexia (Purdy et al., 2009) and reading measures (Hornickel et al., 2012), but the specific use of an FM system during phonological awareness intervention has not been evaluated. This study, therefore, examined the effects of utilizing an FM system during phonological awareness intervention for students at risk for dyslexia.

Participants

The entire class of a first-grade classroom in a school specializing in students with dyslexia was recruited for this study (n = 8). One participant did not demonstrate phonological awareness impairment on eligibility measures and was disqualified. During the baseline phase, three participants achieved 80% mastery or above on two or more skills on three consecutive sessions and were discontinued. Please see Appendix A for the progress monitoring assessment scores for these participants.

Four students were retained in the study after baseline. Participants were six and seven years old, primarily spoke English, had no additional diagnoses known to affect language, and had nonverbal intelligence within the average range. Participants' hearing was screened bilaterally in a quiet room and all children had normal hearing.

Inclusionary and Descriptive Measures

Prior to the initiation of the baseline phase, participants completed an assessment session to determine if they met eligibility criteria and to obtain descriptive measures of language and articulation skills. The Comprehensive Test of Phonological Processing- 2nd Edition was administered to assess phonological awareness and phonological memory (CTOPP-2; Wagner et al., 2013). Coefficient alpha of the phonological composite is .90 to .94; test-retest reliability ranges from .73 to .92 for all subtests and composite scores. The entire core of the CTOPP-2 was administered to obtain phonological awareness, phonological memory and rapid symbolic naming composite scores. Subtests in the phonological awareness composite include: Elision, which assesses saying parts of words with parts and sounds omitted, Blending Words, which blends sounds to form words, and either Phoneme Isolation, identifying the first, last or middle sound in a word, for participants seven years of age or Sound Matching, identifying words that begin or end with the same sound, for participants six years of age. The Phonological

Memory composite includes the subtests Memory for Digits, which assesses digit span, and Nonword Repetition. The Rapid Symbolic Naming composite includes the Rapid Digit Naming and Rapid Letter Naming subtests. To be eligible, participants had to demonstrate phonological awareness weaknesses, determined by a below average score, at or below 89, on the Phonological Awareness Composite of the CTOPP-2. The other two composites were used as descriptive measures.

Nonverbal intelligence was assessed using the Test of Nonverbal Intelligence - 4th Edition (TONI-4; Brown et al., 2010). Test-retest reliability is .86 and coefficient alpha is .96. Participants viewed black and white images of shapes and selected the best image to fill an empty square. To be eligible for participation participants had to demonstrate nonverbal intelligence at or above the normal range as determined by a standard score of 85 of above on the TONI-4.

Participants completed the Test of Word Reading Efficiency - 2nd Edition (TOWRE-2; Torgesen et al., 2012) to describe word-level reading fluency. This measure consists of two timed subtests. During the Sight Word Efficiency Subtest (test-retest reliability = .91), participants read as many sight words as they were able in the given time. During the Phonemic Decoding Subtest (test-retest reliability = .90), participants read as many nonwords as they were able in the given time. Together, these subtests provide information on timed phonemic decoding and sight word recognition and provide a Total Word Reading Efficiency Index.

The Arizona Articulation Proficiency Scale - 4th Edition (Arizona-4; Fudala & Stegall, 2017) was administered to describe word-level articulation skills. Test –

retest reliability is .96. Participants viewed color images and provided the word. When the child responded with an incorrect word, the correct word was provided using a scripted prompt from the Arizona-4 manual.

The Structured Photographic Expressive Language Test - 3rd Edition (test-retest reliability = .94; SPELT-3; Dawson et al., 2003) was administered to describe participants' broad oral language skills but was not used as an inclusionary measure. Participants viewed color photographs and answered questions asked by the examiner. See Table 2.1 for complete scores from descriptive measures for participants of the intervention and Table 2.2 for participants who were discontinued.

Setting

Children participated in the initial assessment in a quiet room in the children's school completed by the author and major professor. Baseline sessions took place individually and intervention sessions took place in small groups in a classroom in the children's school. The intervention sessions were completed by the special education coordinator at the children's school. Sessions were conducted in a group of four and occurred three days a week in the morning during a literacy block. This period was chosen because the children were already broken into small groups for literacy instruction at this time with the special education coordinator.

Table 2.1 Descriptive Information about Participants for Study 1

	P 1	P 2	P 3	P 4
Age in Years, Months	7, 6	7, 1	6, 7	6, 10
TOWRE-2 Total Word Reading Efficiency	77	80	82	75
CTOPP-2 Phonological Awareness	75	80	88	82
CTOPP-2 Phonological Memory	70	82	67	82
CTOPP-2 Rapid Symbol Naming	79	95	98	77
SPELT-3	89	85	96	96
ARIZONA	88	100	61	88
TONI-4	99	86	95	115

Note. TOWRE-2 = Test of Word Reading Efficiency – 2nd Ed. (Torgesen et al., 2012), CTOPP-2 = Comprehensive Test of Phonological Processing – 2nd Ed. (Wagner et a., 2012), SPELT-3 = Structured Photographic Expressive Language Test- 3rd Ed. (Dawson et al., 2003), Arizona = Arizona Articulation and Phonology Scale- 4th Ed. (Fudala & Stegall, 2017), TONI-4 = Test of Nonverbal Intelligence, 4th Ed. (Brown et al., 2010).
P = Participant

Table 2.2 Descriptive Information about Participants Discontinued from Study 1

	P 1	P 2	P 3	P 4
TOWRE-2 Total Word Reading Efficiency	66	77	82	92
CTOPP-2 Phonological Awareness	77	86	73	90
CTOPP-2 Phonological Memory	61	98	70	113
CTOPP-2 Rapid Symbol Naming	82	76	95	98
SPELT-3	93	92	82	84
ARIZONA	100	100	100	75
TONI-4	106	100	94	95

Note. TOWRE-2 = Test of Word Reading Efficiency – 2nd Ed. (Torgesen et al., 2012), CTOPP-2 = Comprehensive Test of Phonological Processing – 2nd Ed. (Wagner et a., 2012), SPELT-3 = Structured Photographic Expressive Language Test- 3rd Ed. (Dawson et al., 2003), Arizona = Arizona Articulation and Phonology Scale- 4th Ed. (Fudala & Stegall, 2017), TONI-4 = Test of Nonverbal Intelligence, 4th Ed. (Brown et al., 2010).
P = Participant

Materials

Intervention. The intervention was a modification of a published phonological awareness training curriculum, the Intensive Phonological Awareness Program (IPAP; Schuele & Murphy, 2014), a 12-week intensive training curriculum that is comprised of 36 developmentally sequenced 30-minute lessons. This curriculum was specifically developed to align with National Reading Panel (2000) recommendations for phonemic awareness, a key component of literacy instruction. Consistent with these recommendations, the phonological awareness training program is explicit, includes segmenting and blending phonemes, explicitly connects activities to reading, and takes place in small groups. The lessons target letter-sound knowledge, awareness of initial sounds, awareness of final sounds, and blending and segmenting sounds in words. The IPAP has been successfully utilized previously in small-group kindergarten intervention with children at risk for reading disabilities (Schuele et al., 2008) as well as preschool children with hearing loss (Werfel & Schuele, 2014; Werfel et al., 2016).

Following Werfel and Schuele (2014) and Werfel and Reynolds (2019), lesson plans were adapted from the existing curriculum. The intervention consisted of lessons targeting segmenting and isolating sounds in words with an initial blend. The teaching words were modified from the published curriculum to include only words that begin with /l/ blends and /r/ blends. Phoneme blends, which are more difficult to analyze than single consonants (Treiman, 1992), were selected that did not show differences in segmentation and representation in a study of kindergarteners with typical development (Werfel & Schuele, 2012). Word-initial /l/ and /r/ blends were selected because 1) both are liquids, 2) they occur in the same location in words, and 3) no difference was reported in their representation in kindergarten student's developmental spellings Werfel and Schuele (2012).

The intervention was intended originally to run for six weeks (18 sessions). Due to school closures related to COVID-19 in March 2020, the intervention instead ran for 11 of the intended 18 sessions, four of the intended six weeks, and did not include a maintenance condition.

Training. Two teachers participated in the training and administered baseline assessments. One was the students' primary classroom teacher, and the other was the special education coordinator. The teachers were provided with the original, published version of the IPAP as well as the adapted lesson plans for the study. The teachers completed a two-day training at their school conducted by the author. The training consisted of learning about the FM system, hands-on training on utilizing the FM system, helping students use the FM system, conducting intervention sessions, and completing assessments. Teachers practiced with each other until they were able to correctly implement the assessment. Proficiency was attained when teachers administered the assessment with 90% accuracy over three consecutive administrations with the author via Zoom for Telehealth.

Although two teachers were trained, the four students that remained in the study were all within the same small-group and had the same teacher. The existing groups of the class had been divided based on scores on reading-based measures; therefore, it was not surprising that the four students that met inclusionary criteria and did not make gains during baseline were in the same small group.

FM Systems. Two Roger Focus FM systems were provided by Phonak for use in this study. These wireless hearing-assistive devices were used to enhance the signal-to-noise ratio in the classroom. Each system contained two receivers and one teacher microphone. During each condition of the intervention sessions, two children at a time were wearing FM systems and two participated without FM systems. Each participant wore two receivers, one on each ear, during their assigned portion of the session. The microphone was worn around the teacher's neck. Each student was provided with their own set of slimtubes and attached domes, small mushroom-shaped silicone pieces that fit inside the ear canal. Between conditions, the teacher changed out the dome and slimtubes of the FM system. These pieces were kept in small boxes labeled with each child's name. Between sessions, the FM systems and components were stored in the teacher's locked office.

Response Definitions and Measurement Systems

Eligibility Testing. Eligibility assessment was conducted by the author and major professor, both certified speech-language pathologists, prior to enrollment in the baseline phase. Testing occurred individually. Testing sessions occurred over two days and lasted approximately one hour and 30 minutes in total for each participant.

Progress Monitoring Assessment. The assessment used in this study was a 30-item curriculum-based progress monitoring phonological assessment developed by the author; it can be found in Appendix B. The progress monitoring measure contained three tasks: segmenting, isolation, and deletion. Segmenting and isolation were targeted during the intervention. Deletion was not targeted and was included to determine generalization of skill. The order of the tasks was alternated each day.

The tasks and script of the assessment were based on the CTOPP-2 (Wagner et al., 2013). Specifically, the directions and questions for the deletion task was based on the Elision subtest, the directions and questions for the isolation task was based on the Phoneme Isolation subtest, and the directions and questions for the segmenting task were based on the Blending Words subtest. These were the same subtests that comprised the Phonological Awareness Composite on the CTOPP-2.

The words in the assessment were based on word lists containing words with blends from Werfel and Schuele (2012). A master list of 60 words was generated containing an equal number of /r/ blend, /l/ blend, and /s/ blend CCVC words. This master list can be found in Appendix C. From this list, 30 words, 10 from each blend, were randomly selected for the progress monitoring assessment. Of the words in the assessment, half of the /l/ and /r/ blend words were targeted during intervention and half were not; none of the /s/ blend words were targeted. Ten words were randomly selected from the progress monitoring assessment list for each task; each progress monitoring measure used all 30 words. The words were presented orally along with a color image with no written words or letters on a 5 x 5-inch index card. The child was instructed to segment the sounds in the word, identify the second sound in the word, or delete the second sound in the word. The students participated in the assessment independently and did not wear the FM system during the assessment. The teacher recorded the child's response during administration and counted and recorded responses immediately following administration. Each word was marked as correct or incorrect. A correct response for segmentation was defined as correct segmentation of all sounds in the target word, such as /g/ /l/ /ʌ/ /g/ for *glug*. A correct response for identification was defined as the correct sound asked for from the word. For example, if the examiner asked for the second sound in the word *glug*, the correct response would be /l/. A correct response for deletion was correct removal of the target sound. For example, the correct response to *glug without /l/* was /gʌg/*.* No response for more than four seconds was scored as incorrect. Repetitions were not allowed. The assessment occurred at the beginning of each session and all assessments were audio recorded to allow for calculation of reliability.

Baseline Procedures. During baseline, children did not participate in intervention and did not wear the FM systems. In the baseline phase, participants completed the progress monitoring assessment individually three times per week, at the same time that intervention would later occur. This took approximately five minutes per child. The children completed the assessment with the teacher who taught their small group during the literacy block. Again, all of the participants retained in this study were in the same literacy block small group and had the same teacher. After all participants obtained 5 baseline points with no indication of a positive trend in segmenting or isolation skills, the intervention phase began.

Procedures of Experimental Conditions. During the intervention phase, the students completed progress monitoring assessments and additionally participated in the phonological awareness training curriculum adapted from Schuele and Murphy (2014). Children participated in small group intervention 30 minutes a day, three days per week. As described in detail above, an adapted alternating treatment design was utilized in order to determine additive effects of an FM system beyond phonological awareness training alone.

Each day, the intervention session included both isolation and segmenting lessons. The order in which skills were targeted alternated each day. Participants were randomly assigned to use the FM system during instruction of one activity throughout the study. For instance, Participant 1 wore the FM system during all lessons that targeted segmenting while Participant 2 wore it for all lessons that targeted isolation. For lessons with the other activity, they received intervention only without the FM system. See Table 2.3 for full details on assignment.

The process for randomization was as follows. First, participants were entered into an excel spreadsheet and the order was randomized. Next, segmenting was assigned the number one or two using a random number generator. After that, a number (1-2) was randomly selected using a random number generator that indicated during which lesson the first participant in the list would wear the FM. This was repeated for Participant 2. Then, the number one or two was randomly selected using a random number generator to indicate whether Participant 3 would alternate with Participant 1 or 2. This was repeated for Participant 4 as needed.

Table 2.3 Assignment of Intervention Conditions

	Segmenting	Isolation	Deletion
Participant 1	FM + instruction	No FM + instruction	No instruction
Participant 2	No FM +instruction	FM + instruction	No instruction
Participant 3	FM + instruction	No FM + instruction	No Instruction
Participant 4	No FM + instruction	FM + instruction	No instruction

Procedural Fidelity. Procedural fidelity was completed by a trained lab member who watched a recording of the sessions and completed a checklist of behaviors that should be evidenced during the session. See Appendix C for a checklist of behaviors measured. Procedural fidelity was measured in 60% of sessions. Percentage of compliance with experimental protocol (total # of instances of compliance/ [# of instances of compliance + # of instances of noncompliance], multiplied by 100) was 95.9%.

Inter-Observer Agreement. Inter-observer agreement (IOA) was calculated for both correct and incorrect responses on the progress-monitoring assessments using the point-by-point method (# agreements/ [number of agreements + number of disagreements], multiply by 100). The author measured overall IOA in 95% of sessions live via Zoom. IOA between the author and the special education coordinator was 98%.

Analysis

Two methods of analysis were used. Visual analysis was conducted and supplemented with Tau-U effect size analysis (Parker et al., 2011). To complete visual analysis, data was graphed and differences of trend, level, and variability were compared between conditions for each participant, consistent with accepted standards of analysis for single-case designs (Horner et al., 2005). An independent researcher previously uninvolved with this project, who has received explicit training in single-case design methodology and has successfully published a single-case design study, completed visual analysis as well and the findings were compared. In addition, visual analysis was supplemented by Tau-U analysis, a nonparametric analysis that provides a measure of data nonoverlap and accommodates for baseline trends. Tau-U effect size values range from –1 to 1; positive values indicate increase in outcome variable. Tau-U values of 0.20 are considered small, 0.20–0.60 moderate, and 0.80 and above large/very large (Vannest & Ninci, 2015).

Study 2

Study 2 investigated the additive effect of a simulated classroom FM system during phonological awareness training compared to simulated classroom background noise in individual phonological awareness intervention delivered via telepractice. Furthermore, Study 2 sought to determine if children at risk of dyslexia made progress in phonological awareness skills following a phonological awareness intervention that was delivered virtually.

Participants

Participants were recruited from social media parent groups including school district groups, homeschooling idea groups, and support groups for parents of children with reading impairment. Twelve first-grade students underwent eligibility testing for this study. All parents reported that their children struggled with literacy skills and reported no history of hearing loss. At the time of the initial eligibility testing, participants were six or seven years old, enrolled in first grade, spoke English at home, resided in the United States, and had no diagnoses known to affect language. Hearing was not assessed.

After initial contact was established between the parent and the author, potential participants completed an assessment session to determine if they met eligibility criteria and to obtain descriptive measures of language and articulation skills. As in Study 1, the CTOPP-2 was administered to assess phonological awareness and phonological memory (Wagner et al., 2013), TONI-4 to assess nonverbal intelligence (Brown et al., 2010), the Arizona-4 was used to describe word-level articulation skills (Fudala & Stegall, 2017), and the SPELT-4 was administered to describe oral language skills (Dawson et al., 2003). Refer to Study 1 for full details about each assessment.

Of the twelve children that were tested, three were eligible to participate in the intervention portion of the study. Eligibility for participation was the same as Study 1 and included: nonverbal IQ within the normal range as determined by the Test of Nonverbal Intelligence – 4th Edition (a standard score at or above 85; TONI-4; Brown et al., 2010) and phonological awareness weaknesses determined by a below average score, at or below 89, on the Phonological Awareness Composite of the Comprehensive Test of Phonological Processing- 2nd Edition (CTOPP-2; Wagner et al., 2013). See Table 2.4 for full details of eligibility and descriptive measures for participants retained in the study.

Six of the children scored in the average or above average range on the CTOPP-2 Phonological Awareness Composite and were ineligible to continue in the study. Interestingly, two of those six children obtained standard scores that placed them in the 98th percentile. Of the remaining six children, one had difficulty completing the initial progress monitoring assessment. Her mother reported that she struggled with the concepts of “second” and “first.” After the initial baseline session, the author and parent decided she would not be a good fit for the intervention based on limited knowledge of key intervention-specific conceptual vocabulary. One child who otherwise met eligibility criteria achieved 80% accuracy or higher on the isolation portion of the initial daily assessment during baseline and was subsequently discontinued. The final child that met eligibility criteria was discontinued due to unintelligibility of responses during the daily assessment resulting from cluster-reduction articulation errors. Please see Table 2.5 for children whose participation in the study was discontinued. Three children that met eligibility criteria were retained in the study and completed all baseline, intervention, and maintenance phases.

Setting

All assessment, baseline, intervention, and maintenance sessions were completed by the author, a certified speech-language pathologist, remotely via Zoom for Telehealth, a version of Zoom with advanced security features. During the sessions, the participant was at his or her house on a laptop computer or iPad. Each session was conducted individually with one participant. For the progress monitoring assessment portion of the session, the author shared her screen with

Table 2.4 Descriptive Information about Participants in Study 2

	Participant 1	Participant 2	Participant 3
Age	6, 10	7, 3	6, 3
TOWRE-2 Total Word Reading Efficiency	83	73	85
CTOPP-2 Phonological Awareness	88	80	88
CTOPP-2 Phonological Memory	85	79	70
CTOPP-2 Rapid Symbol Naming	85	92	104
SPELT-3	96	77	98
ARIZONA	81	100	100
TONI-4	93	94	123

Note. TOWRE-2 = Test of Word Reading Efficiency – 2nd Ed. (Torgesen et al., 2012), CTOPP-2 = Comprehensive Test of Phonological Processing – 2nd Ed. (Wagner et a., 2012), SPELT-3 = Structured Photographic Expressive Language Test- 3rd Ed. (Dawson et al., 2003), Arizona = Arizona Articulation and Phonology Scale- 4th Ed. (Fudala & Stegall, 2017), TONI-4 = Test of Nonverbal Intelligence, 4th Ed. (Brown et al., 2010).

images of the target words. The participant saw both the image and the author's face. During the intervention, the researcher shared her screen which contained PowerPoint slides containing the activity for that day's lessons. The participant saw both the slides and the author's face. During the intervention, the participant utilized the draw and stamp functions of Zoom as needed to interact with the materials shared on the screen.

Materials

Zoom for Telehealth. All of the sessions occurred virtually using Zoom for Telehealth. Parents of participants were typically present or nearby in the room to set up Zoom initially, complete background noise measurements, and troubleshoot technological issues.

Decibel X. A smartphone-based app, Decibel X, was used to measure the background noise in participants' homes, the author's voice through their computer speakers, and the background noise through their speakers. This application has been used in virtual data collection to measure sound levels of background noise and assessor's voice (Werfel et al., in press). The parent was instructed to download the Decibel X application to their phone. First, the background noise in the participant's home was measured. If it was not between 30 and 35 dB, suggestions were made to the parents about shutting off background TV or closing doors to other rooms where siblings were playing, consistent with recommendations in Werfel et al. (in press). Next, a measurement was taken from the participants' speakers while the author was reading a passage. Then, the author played the background noise in either the low or high condition. Based on the measurement taken from the author reading a passage, the parent was instructed to adjust their computer speakers until it was playing at the correct volume and signal-to-noise ratio. After completion of the first lesson, the author played the background noise for the second condition and another measurement of the background noise was taken.

Table 2.5. Descriptive Information about Participants Discontinued from Study 2

	P 4	P 5	P 6	P 7	P 8	P 9	P 10	P 11	P 12
Age	6, 4	7, 1	6, 7	6, 4	6, 9	6, 7	6, 3	7, 0	6, 3
TOWRE-2 Total Word Reading Efficiency	81	68	77	74	101	91	88	-	91
CTOPP-2 Phonological Awareness	127	84	71	56	112	107	96	90	122
CTOPP-2 Phonological Memory	98	88	70	52	98	88	39	25	98
CTOPP-2 Rapid Symbol Naming	-	79	82	58	-	110	79	82	107
SPELT-3	86	100	63	<40	-	-	94	-	-
ARIZONA	60	82	69	74	-	100	81	-	-
TONI-4	114	102	100	90	97	109	111	94	-

Note. TOWRE-2 = Test of Word Reading Efficiency – 2nd Ed. (Torgesen et al., 2012), CTOPP-2 = Comprehensive Test of Phonological Processing – 2nd Ed. (Wagner et a., 2012), SPELT-3 = Structured Photographic Expressive Language Test-3rd Ed. (Dawson et al., 2003), Arizona = Arizona Articulation and Phonology Scale- 4th Ed. (Fudala & Stegall, 2017), TONI-4 = Test of Nonverbal Intelligence, 4th Ed. (Brown et al., 2010).
P = Participant

Background Noise. A recording of background noise was created in Apple's music recording and editing software, GarageBand. A recording of 'hallway crowd' background noise obtained from pacdv.com was overlaid with a recording of an HVAC unit. The hallway crowd background noise did not contain intelligible speech. This selection of background noise included two sources of noise, an external source, noise typical of a school hallway, and an internal source, an HVAC unit. The inclusion of both types of noise was intended to simulate the multiple sources of background noise representative of a typical classroom environment (Shield & Dockrell, 2003).

The background noise soundfile was played from the interventionist's computer. Then, she shared her screen with the participant using the share screen function on Zoom. With this function, she was also able to share the sound with the participant. This method allowed the sound to be played directly from the participant's computer speakers as if they were playing the sound from their own computer. The author could adjust the volume from her own computer.

Intervention. The phonological awareness training program that was used in Study 1, the IPAP, was utilized (Schuele & Murphy, 2014). Please see Study 1 for detailed description about this program. The training program was adapted further in Study 2 to be used in a virtual one-on-one format.

Several adjustments to the materials were made to allow for virtual delivery. In Study 1, during the daily assessment, the teachers held index cards with a printed color image of the target word. Prior to each daily assessment, the teachers shuffled their deck of index cards. In Study 2, these images were converted to

PowerPoint slides. The author created a randomize function within the PowerPoint presentation. Prior to each daily assessment, the author randomized the order of presentation of the images.

Additionally, the IPAP lessons utilize several images and activities that are typically presented on paper. For the virtual delivery of the intervention, all activities were converted to PowerPoint slides or Word documents. The activities utilized included: slides of three or four squares of colors used to segment and identify sounds in words, “sound box” slides which contained a picture of a word along with the same number of black and white boxes as there are in the word, and “sound puzzles” which contained an image divided into as many pieces as there were sounds in the word. See Appendix D for an example of each image. The researcher and students used their mouse, the stamp feature, or draw feature on Zoom when completing activities. For instance, the researcher would place a stamp in each box as she said each sound in a given word.

Response Definitions and Measurement System

Eligibility Testing. Eligibility assessments were conducted by the author prior to enrollment in the baseline phase. Testing sessions lasted approximately one hour and 30 minutes over one or two sessions. Testing was completed via Zoom for Telehealth. The test booklet was displayed via camera. Participants provided their answer orally or by selecting an answer using the stamp function in Zoom.

Progress Monitoring Assessment. The assessment used in this study was the author-developed 30-item curriculum-based progress monitoring phonological assessment described in detail in Study 1 and found in Appendix A. The researcher recorded the child's response during administration and counted and recorded responses immediately following administration. Each word was marked as correct or incorrect. The assessment occurred at the beginning of each session and all assessments were recorded. Notably, repetitions were allowed in this virtual component of this study. There were multiple instances where the target word or child's response was inaudible and had to be asked for again. This occurrence is due to the audio suppress feature of Zoom; when Zoom detects a sudden loud noise, it briefly cuts off all audio. This was the only way in which the assessment differed from its in-person administration.

Baseline Procedures. During baseline, children did not participate in intervention. Participants completed the progress monitoring assessment individually three times per week, at the same time that intervention would later occur. Participants entered the intervention phase after obtaining 5 baseline points that did not indicate an upward trend in segmenting or isolation.

Procedures of Experimental Conditions. During the intervention phase, the participants participated in the phonological awareness training curriculum adapted from Schuele and Murphy (2014). Children participated in intervention 30 minutes a day, three days per week, as in Study 1. The instruction separately targeted two phonological awareness skills, segmenting and isolation, with a focus on initial blends, which are more difficult to analyze than single consonants

(Treiman, 1992). Each day, the intervention session included both isolation and segmenting lessons; the order was alternated.

Participants were randomly assigned to conditions during lessons targeting segmenting and isolation. One condition was intended to simulate a classroom environment with the student receiving the auditory benefit of an FM system. In this condition, the background noise was played 15-20 dBA lower than the interventionist's voice, consistent with the signal-to-noise ratio typically provided by an FM system in the classroom (Hawkins, 1984). This condition will be referred to as low background noise. The other condition was intended to simulate background noise in a classroom environment. The background noise was played through the participant's speakers at a level six to ten dBA lower than the level of the interventionist's voice, this signal-to-noise ratio is consistent with that reported in Picard and Bradley (2016) of a typical elementary school classroom. This condition will be referred to as high background noise. Figure 2.1 shows long term average spectra for the background noise played at the volume of the two conditions overlaid with the author's speech. As is evident from the graphs, there is more masking of the author's speech in the high background noise condition compared to the low background noise condition.

Each participant was assigned to be in one condition during instruction of one skill throughout the study. For instance, Participant 1 experienced high background noise during all lessons that targeted segmenting and experienced low background noise during all lessons targeting isolation. See Table 2.6 for full details on assignment.

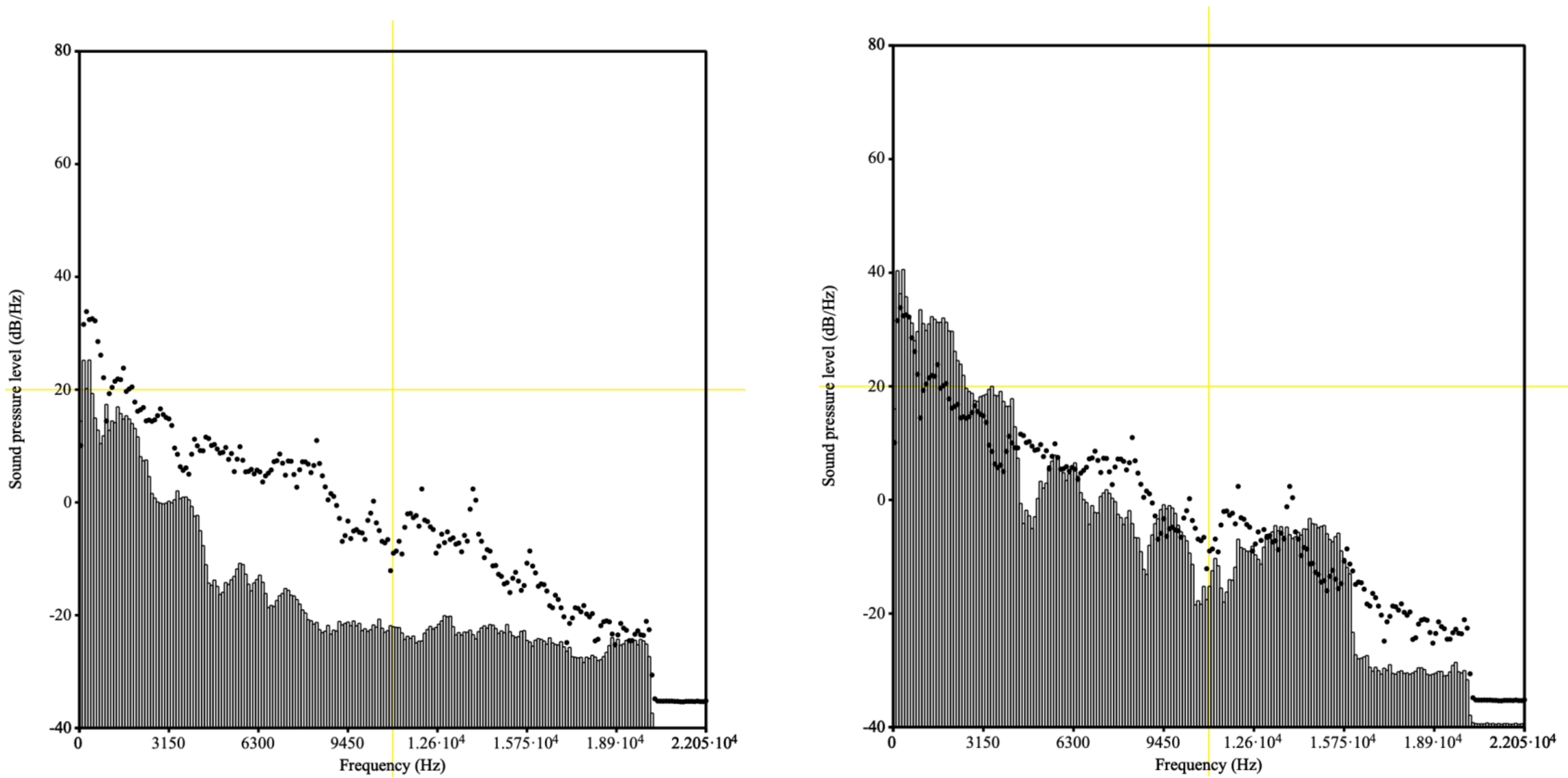


Figure 2.1 Long term average spectra for low background noise condition (left) and high background noise condition (right)

Table 2.6. Assignment of Intervention Conditions

	Segmenting	Isolation	Deletion
Participant 1	High background noise	Low background noise	No instruction
Participant 2	High background noise	Low background noise	No instruction
Participant 3	Low background noise	High background noise	No Instruction

Inter-Observer Agreement. Agreement was calculated for both correct and incorrect responses on the progress monitoring measures using the point-by-point method (i.e., divide # agreements by number of agreements + number of disagreements and multiply by 100) on each participant in 30% of sessions spanning all conditions. All sessions were recorded via Zoom. A trained lab member scored the daily assessments from 30% of conditions for each participant. The researcher calculated IOA between those scores and the scores the researcher obtained during administration. Overall IOA was calculated to be 93.8% and ranged from 90% to 96.6% across participants.

Procedural Fidelity. Procedural fidelity was measured live in 30% of sessions for each participant. See Appendix E for a checklist of behaviors measured. Percentage of compliance with experimental protocol (total # of instances of compliance/# of instances of compliance + # of instances of noncompliance, multiplied by 100) was calculated for each variable with means and ranges of occurrences for each participant in each condition. A trained lab member viewed the intervention sessions and completed procedural fidelity. Unlike Study 1, procedural fidelity was completed for each participant because they participated individually in the intervention. Procedural fidelity was calculated to be 95.8% overall and 95.8% for each participant.

Considerations of Virtual Delivery

Several differences with remote delivery of the intervention emerged. First, sound-based analysis involves identifying and manipulating isolated sounds in assessment or intervention. The child was prompted to ensure hands were not covering his or her face and to not lean on his or her chin to ensure full range of mobility of the jaw and maximize audibility and to have his or her entire face in the screen during the assessment or intervention. Secondly, there were several rare occasions of the sound cutting out on a Zoom call. The word or sound in question had to be repeated by the researcher or the child. Furthermore, two of the children struggled with attention during their participation in the study. This was true even during the 10-minute daily assessments. When attention was an issue, fewer options to engage attention were available via virtual delivery. For instance, the participant was able to physically leave the room or hide out of the view of the screen. To address these issues, a parent was near the child during the intervention. In all instances, the parent was successful in engaging the child by reminding them of their agreement regarding their participation or what was scheduled after they were finished. However, when these instances occurred, they caused delays lasting up to several minutes.

Virtual delivery also limited the types of feedback the author was able to provide. For instance, during the in-person intervention, the teacher and students were able to place their fingers on the different boxes when segmenting words, tap out the sounds on their desk, or tap their feet. The teacher was also able to draw the students' attention to her mouth. The teacher was able to determine from the direction of the child's gaze and body language whether or not they were attending to the correct stimulus. The author used her mouse and the stamp feature on Zoom to identify each sound in a word on a different box. However, she was unable to use other modalities such as finger or foot tapping. More importantly, it was difficult to determine whether the child was attending to the right location on the screen.

Analysis

Two methods of analysis were used. First, visual analysis was conducted and was then supplemented with Tau-U effect size analysis (Parker et al., 2011). To complete visual analysis, data was graphed and differences of trend, level, and variability were compared between conditions for each participant, consistent with accepted standards of analysis for single-case designs (Horner et al., 2005). Visual analysis was again compared with the findings of the independent researcher mentioned in Study 1.

Comparison of Blend Words in Progress Monitoring Assessment Across Studies

To address this research question, the performance on the progress monitoring assessment was compared across blends, /l/, /r/, and /s/ blends, of the for each task and each participant. The intervention only targeted words with an /l/ or /r/ word initial blend, but the progress monitoring assessment included words with /l/, /r/, and /s/ blends. For those participants that did make progress, the accuracy on words containing each sound were compared to determine if higher accuracy was first achieved on the sounds targeted in the intervention. The number of correct /l/, /r/, and /s/ words were graphed separately for both tasks targeted during intervention for each participant that made progress.

CHAPTER 3

RESULTS

Study 1

The progress monitoring assessment data for Participants 1 and 2 is presented in Figure 3.1 and for Participants 3 and 4 in Figure 3.2. The Tau-U effect sizes for the two skills targeted in intervention are presented in Table 3.1. Visual analysis revealed and was corroborated by Tau-U effect sizes that for those participants who benefitted from the intervention, more immediate, consistent, and greater growth was evident in the skill learned while using the FM system. Visual analysis was corroborated with the findings of the independent researcher.

Participant 1

FM Condition- Segmenting. Participant 1 wore the FM system during lessons targeting segmenting. During baseline, Participant 1 scored at 30% or lower on segmenting. During intervention, she continued at baseline-level performance for three sessions before a substantial increase in segmenting skill, increasing from 20% to 90% after three intervention sessions. She maintained performance at 80% or higher for the remaining five sessions of the intervention phase. Tau-U indicated a moderate effect size for the phonological awareness intervention and the FM system.

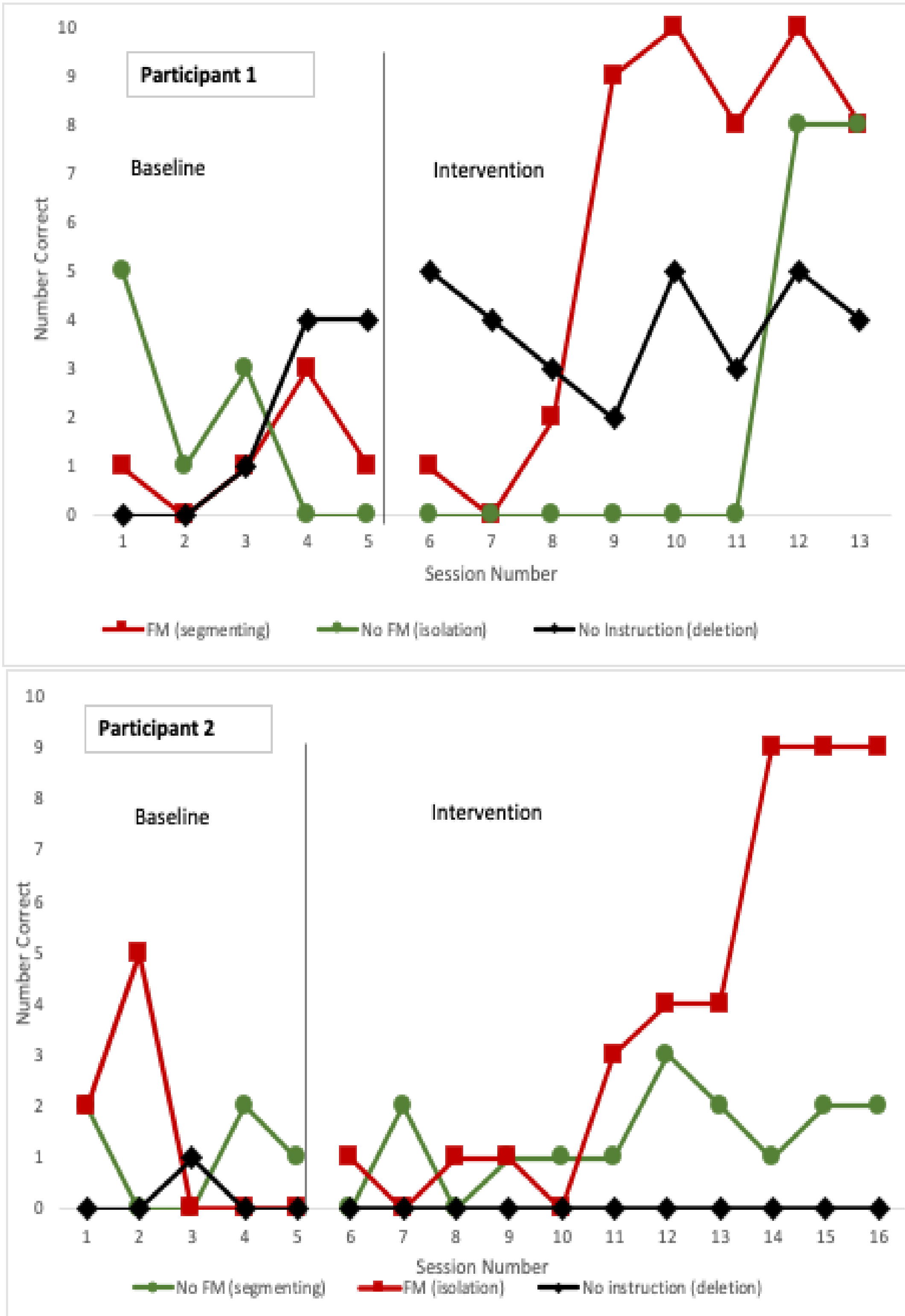
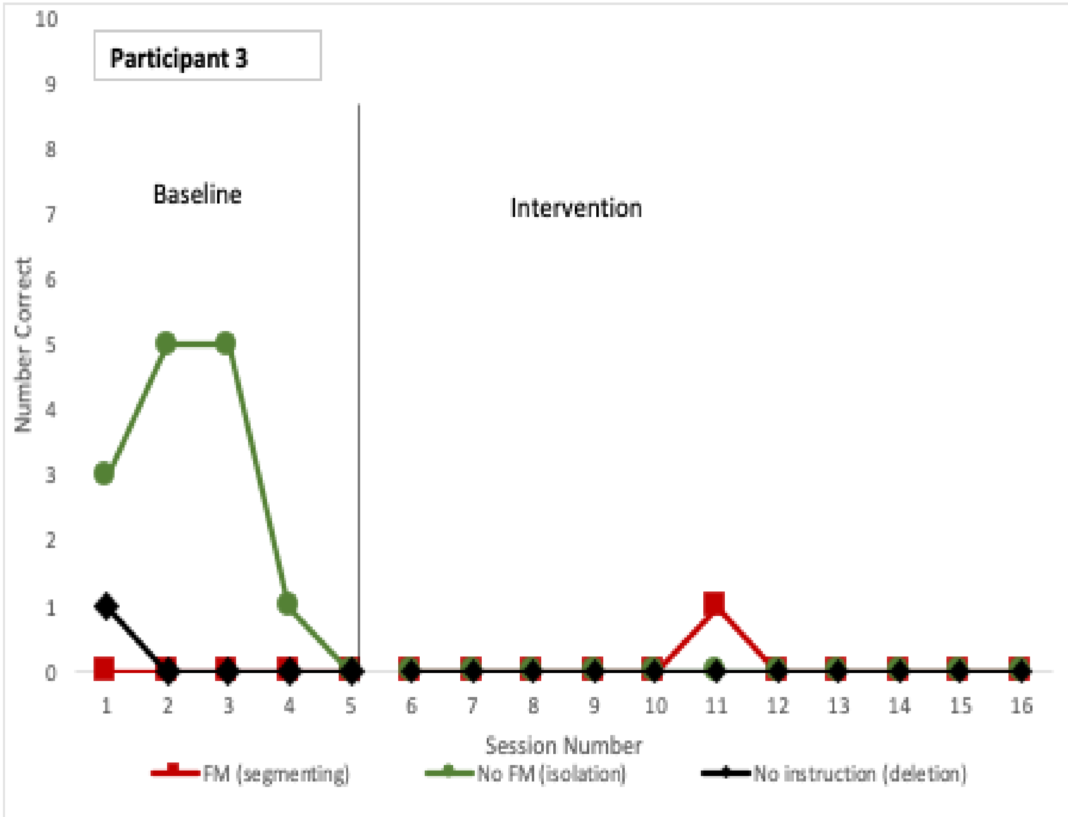


Figure 3.1 Progress monitoring assessment data for Participants 1 and 2



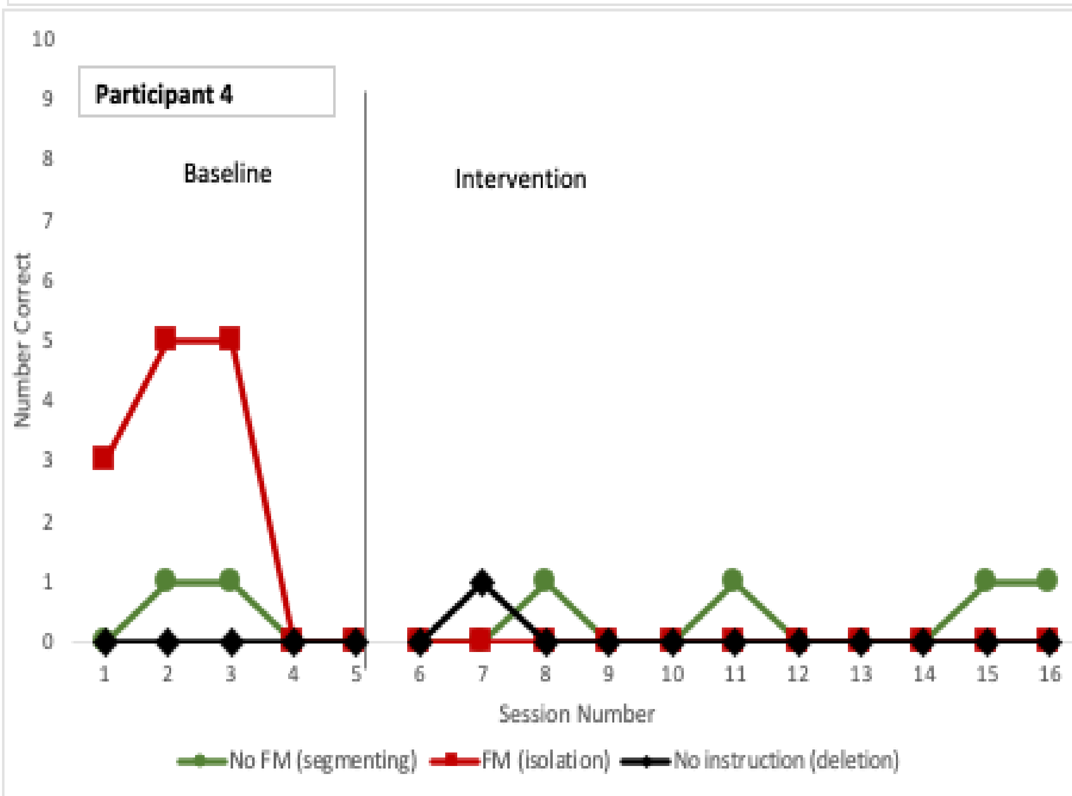


Figure 3.2 Progress monitoring assessment data for Participants 3 and 4

Table 3.1 Tau-U effect sizes of two skills targeted in intervention

	FM condition	**No-FM condition**
Participant 1	0.60	0.20
Participant 2	0.40	0.20
Participant 3	0.09	-0.8
Participant 4	-0.6	0

Non-FM Condition- Isolation. Participant 1 did not score above 50% on isolation during the baseline condition. In the intervention condition, she scored 0% until the sixth session. At the seventh session, Participant 1 scored 80% on isolation. She maintained her score of 80% in the next, and final, intervention session. Tau-U indicated a small effect of the phonological awareness intervention alone.

No Instruction Condition- Deletion. Participant 1 scored at 10% or lower for the first three baseline sessions and 40% for the last two baseline sessions on deletion. During intervention, she demonstrated performance that ranged from 20% to 50%. Performance for deletion never increased beyond 50%.

Participant 2

FM Condition-Isolation. Participant 2 wore the FM for lessons targeting isolation. During baseline, he scored at 50% or lower on isolation. He scored 0% the last two baseline sessions. During intervention, he scored at 10% or lower until session five. Then, performance increased to 30%-40% for three sessions. Following that, he scored 90% on isolation for the last three sessions of intervention. Tau-U indicated a moderate effect of phonological awareness intervention and the FM system.

Non-FM Condition-Segmenting. During baseline, Participant 2 did not score above 20% on segmenting. In the intervention condition, he did not score above 30%. Tau-U indicated a small effect of the phonological awareness condition alone.

No Instruction Condition-Deletion. Participant 2 did not score above 10% on deletion during baseline. In the intervention condition, he did not score higher than 0% on this skill.

Participant 3

FM Condition-Segmenting. Participant 3 wore the FM system for lessons targeting segmenting. Participant 3 scored 0% on segmenting during baseline. She did not score above 10% during intervention. Tau-U indicated no effect.

N**on-FM Condition-Isolation**. Participant 3 scored at 50% or below on isolation during baseline. In intervention, she did not score above 0%. Tau-U indicated a negative effect.

No Instruction Condition-Deletion. Participant 3 did not score above 10% on segmenting during the baseline condition. She scored 0% on deletion throughout the intervention session.

Participant 4

FM Condition-Isolation. Participant 4 wore the FM system for lessons targeting isolation. He scored between 30% and 50% for the first three baseline sessions. He scored 0% on isolation for the last two baseline sessions. He scored

0% on isolation throughout the intervention condition. Tau-U indicated a moderate negative effect.

Non-FM Condition-Segmenting. Participant 1 did not score above 10% on segmenting during baseline. He performed similarly during intervention, he did not score above 10% on segmenting. Tau-U indicated no effect.

No Instruction Condition-Deletion. During baseline, Participant 4 did not score above 0%. During intervention, he scored 10% on the second session. For the remaining sessions, he scored 0% on deletion.

Summary of Findings

Participants 1 and 2 demonstrated quicker, more pronounced, and consistent growth when using the FM system. This finding was supported by Tau-U analysis which revealed moderate effect sizes for the two skills taught in conjunction with the FM system for Participants 1 and 2. For these participants, the level of their performance was higher for the skill targeted with the FM system than the level achieved for the skill targeted without the FM system or the skill not targeted.

Participants 3 and 4 showed a different pattern of skill acquisition. These participants did not make gains on any of the skills throughout the duration of the intervention. For both participants, performance on the daily assessment remained low across the three skill areas.

Study 2

The progress monitoring assessment data for the three participants is presented in Figure 3.3. The Tau-U effect sizes for the two skills targeted in intervention are presented in Table 3.2. Visual analysis revealed that participants made gains on phonological awareness skills targeted during the virtual intervention. Furthermore, the results from these participants were more variable than the results from the participants of the in-person version of this intervention. Participants 1 and 2 made gains during the intervention but no difference between condition was observed. Visual analysis was corroborated with the findings from the independent researcher.

Participant 1

Low Background Noise- Isolation. Participant 1 experienced low background noise during lessons targeting isolation. He scored 20% or below throughout the baseline phase. In intervention, he scored at 20% or below until the seventh session. Then, he scored between 10% and 50% until the last intervention session, when he reached 70%. In the maintenance phase, Participant 1 scored at 70% or above, attaining 100% and 90% the last two sessions. Tau-U indicated a moderate effect from intervention to baseline and large effects from intervention to maintenance and baseline to maintenance.

High Background Noise- Segmenting. Participant 1 experienced high background noise during lessons targeting segmenting. He did not score above 0% during baseline. During the first five sessions of the intervention phase, he did not score above 20%. From session six to the end of the condition, his score varied from 80% to 0%. The last three sessions of intervention Participant 1 scored between 30% and 40%. During maintenance, his score varied between 40% and 70%; he scored 70% the last two sessions. Tau-U indicated moderate-large effects from baseline to intervention and intervention to maintenance and a large effect from baseline to maintenance.

No Instruction Condition- Deletion. Participant 1 did not score above 10% on deletion during baseline. In intervention, he did not score above 20% throughout the entire condition. In the maintenance phase, he scored between 0% and 60%. He scored 20% the final two sessions.

Participant 2

Low Background Noise- Isolation. Participant 2 experienced low background noise during lessons targeting isolation. She did not score above 0% during baseline. She scored at 10% or below until the ninth session in intervention. Beginning at the tenth session, her score increased initially to 20% and eventually to 90%. In the maintenance phase, she scored between 50% and 80%. Tau-U indicated moderate effects from baseline to intervention and intervention to maintenance and a large effect from baseline to maintenance.

High Background Noise- Segmenting. Participant 2 experienced high background noise for lessons targeting segmenting. She did not score above 0% during baseline. She did not score above 0% during the first nine sessions of the intervention. Then, she scored between 10% and 100% during the remainder of the intervention. In the maintenance phase, she scored between 40% and 90%. Tau-U indicated moderate effects from baseline to intervention and intervention to maintenance and a large effect from baseline to maintenance.

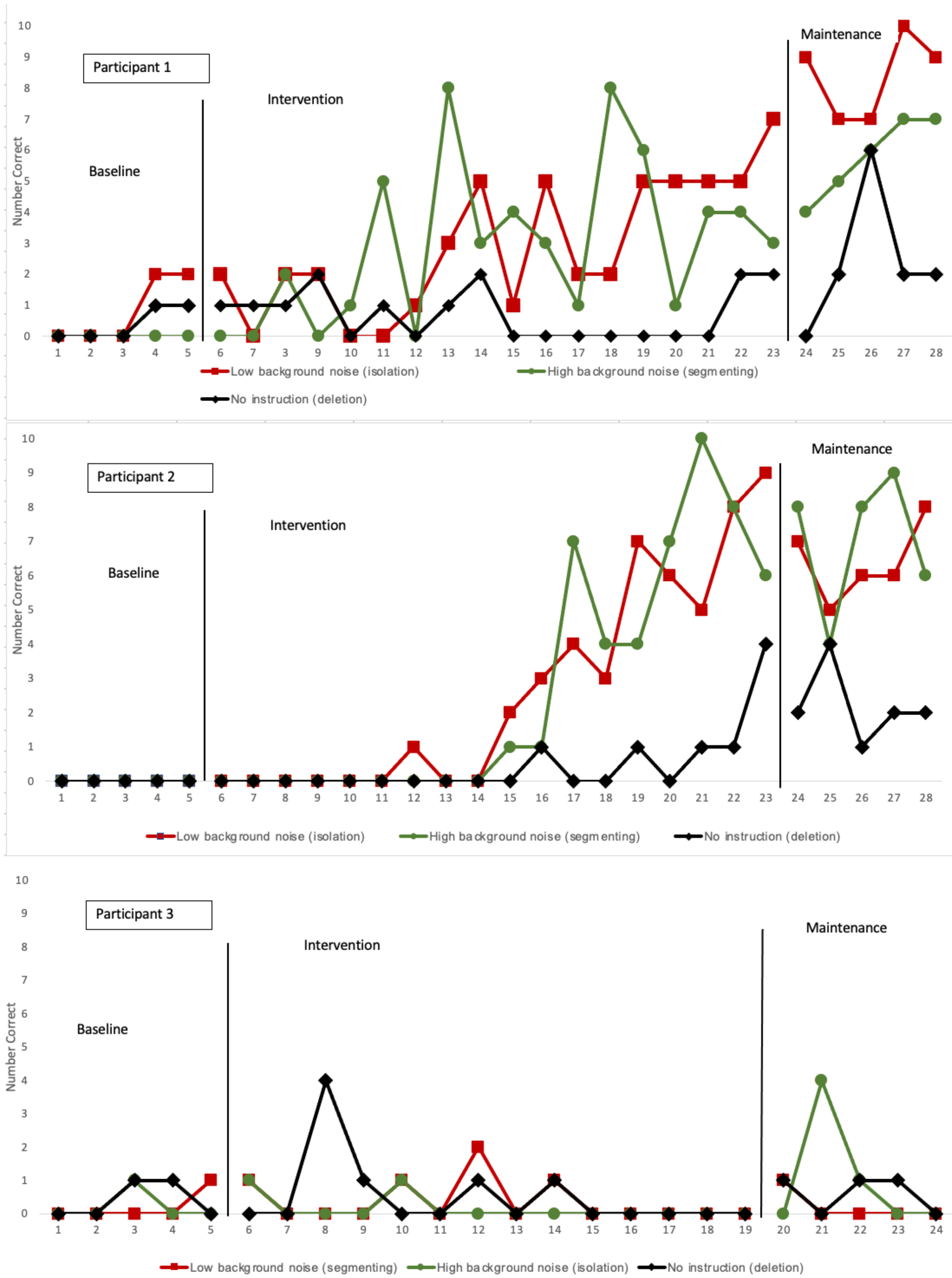


Figure 3.3 Progress monitoring assessment data for Study 2 Participants

Table 3.2 Tau-U effect sizes for Study 2 participants

	Low background noise			**High background noise**		
	Baseline to intervention	Intervention to maintenance	Baseline to maintenance	Baseline to intervention	Intervention to maintenance	Baseline to maintenance
Participant 1	0.56	0.98	1	0.78	0.65	1
Participant 2	0.55	0.65	1	0.5	0.67	1
Participant 3	0.1	-0.1	0	-0.05	0.28	0.24

No Instruction Condition- Deletion. Participant 1 did not score above 10% on deletion during baseline. In intervention, he did not score above 20% throughout the entire condition. In the maintenance phase, he scored between 0% and 60%. He scored 20% the final two sessions.

Participant 3

Low Background Noise- Segmenting. Participant 3 experienced low background noise for lessons targeting segmenting. He did not score above 10% during baseline. During intervention, he did not score above 20% on segmenting. During maintenance, he did not score above 10%. Tau-U indicated no effect between any phases.

High Background Noise- Isolation. Participant 3 experienced high background noise for lessons targeting isolation. He did not score above 10% during baseline. During intervention, he did not score above 10% on isolation. During maintenance, he once scored 40% but scored 0% the final two sessions.

No Instruction Condition- Deletion. Participant 3 did not score above 10% during baseline on deletion. During intervention, he scored 40% once, otherwise did not score above 10%. During maintenance, he did not score above 10%. Tau-U indicated no effect from baseline to intervention and a small effect from intervention to maintenance and baseline to maintenance.

Summary of Findings

Participant 1 demonstrated growth on the skills taught and maintained performance on acquired skills throughout the maintenance phase, which took place approximately one month after the end of the intervention phase. Tau-U analysis for Participant 1 revealed moderate to very large effect sizes for both skills targeted. Participant 2 also demonstrated growth on the skills taught as well as maintenance of learned skills. Tau-U analysis for Participant 2 corroborated these findings, with moderate to large effect sizes for both skills targeted. Participant 3's performance did not demonstrate a trend or change in level throughout all conditions and skills. Tau-U analysis confirmed findings from visual analysis for Participant 3, revealing only a small effect on isolation, learned in in the *high background noise condition, and* no effect on the other skills.

Comparison of Blend Words in Progress Monitoring Assessment Across Studies

The performance of the participants on each target blend, /l/, //r,/ and /s/, was compared for each task. The intervention only targeted words with an /l/ or /r/ word initial blend, but the progress monitoring assessment included words with /l/, /r/, and /s/ blends. For the two participants from each study that did make progress, the number of correct words from each blend type for isolation and segmenting was compared.

For Study 1 participants, depicted in Figure 3.4, there was not a difference in their accuracy on words with an /l/ or /r/ blend and words with an /s/ blend throughout baseline or the intervention phases. Both participants appeared to make similar growth across words with all three sounds for both segmenting and isolation. However, both of the participants in Study 2, depicted in Figure 3.5, demonstrated higher accuracy earlier on with words with /l/ and /r/ blends compared to words with /s/ blends. That is, they were first able to complete

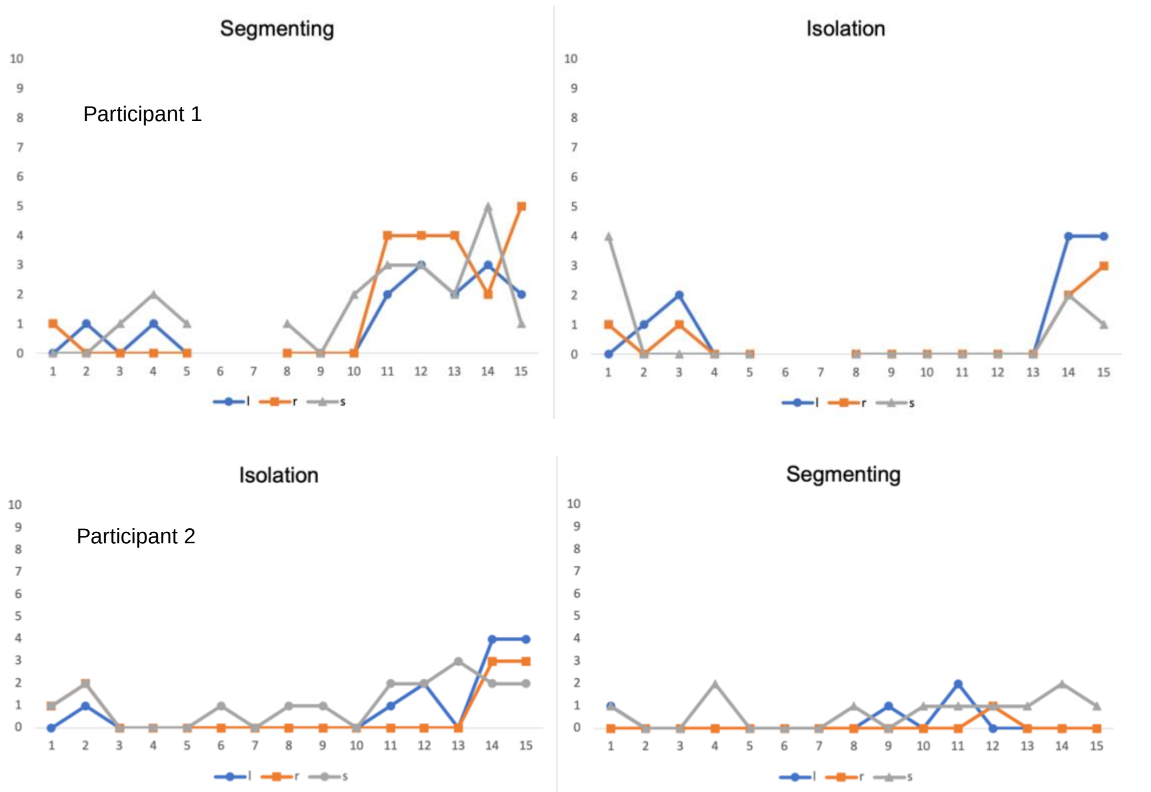


Figure 3.4 Number of Correct Responses by Word Blend for Study 1 Participants Who Showed Improvement

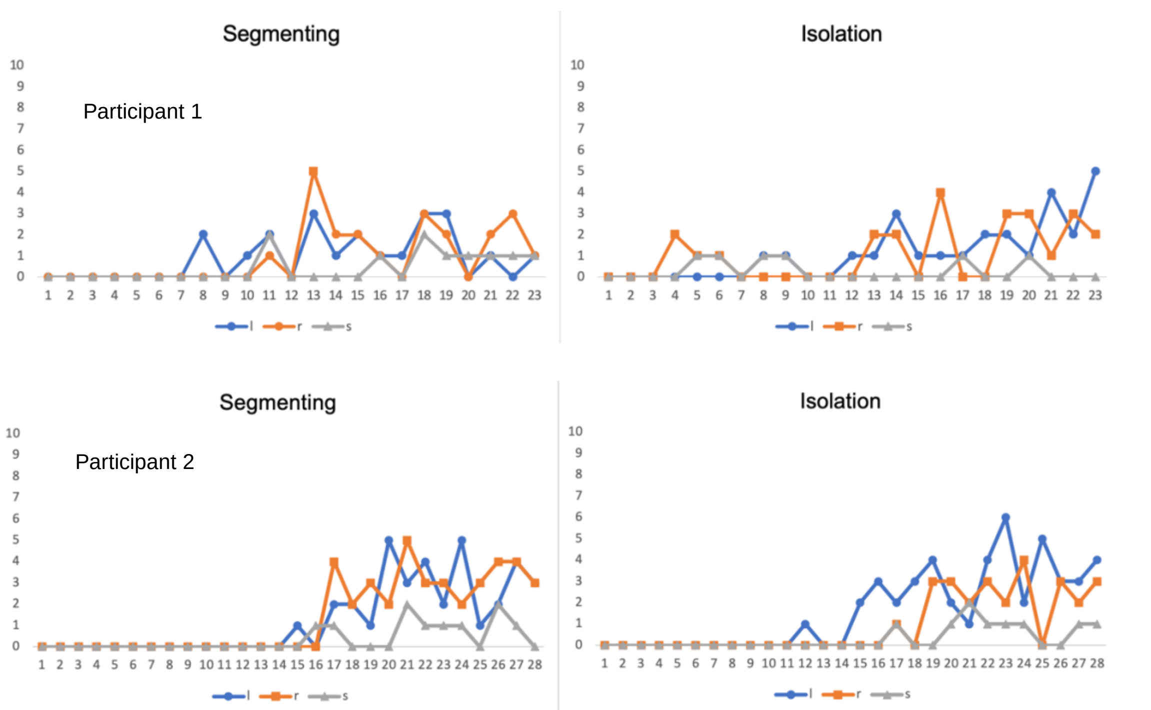


Figure 3.5 Number of Correct Responses by Word Blend for Study 2 Participants Who Showed Improvement

segmenting and isolation tasks with blends that were explicitly targeted during the intervention.

For Study 2 participants, a subsequent analysis was conducted to determine their percent accuracy on the /l/, /r/, and /s/ blends in segmenting and isolation tasks. The randomization of the progress monitoring assessment word list resulted in an unequal number of words with each sound across each task. Therefore, the subsequent analysis provided a measure of percent accuracy for the number of opportunities they were given for each blend type. This subsequent analysis corroborated the initial findings and can be found in Figure 3.6. For both participants, higher accuracy was achieved more quickly on sounds targeted during the intervention compared to the sound that was not for both segmenting and isolation. Additionally, this analysis revealed that their accuracy on /s/ blend words did not approach the accuracy for the targeted blend types. Even at the end of the intervention, accuracy on /s/ blend words remained lower than accuracy on /l/ and /r/ blend words for Participants 1 and 2 on both tasks.

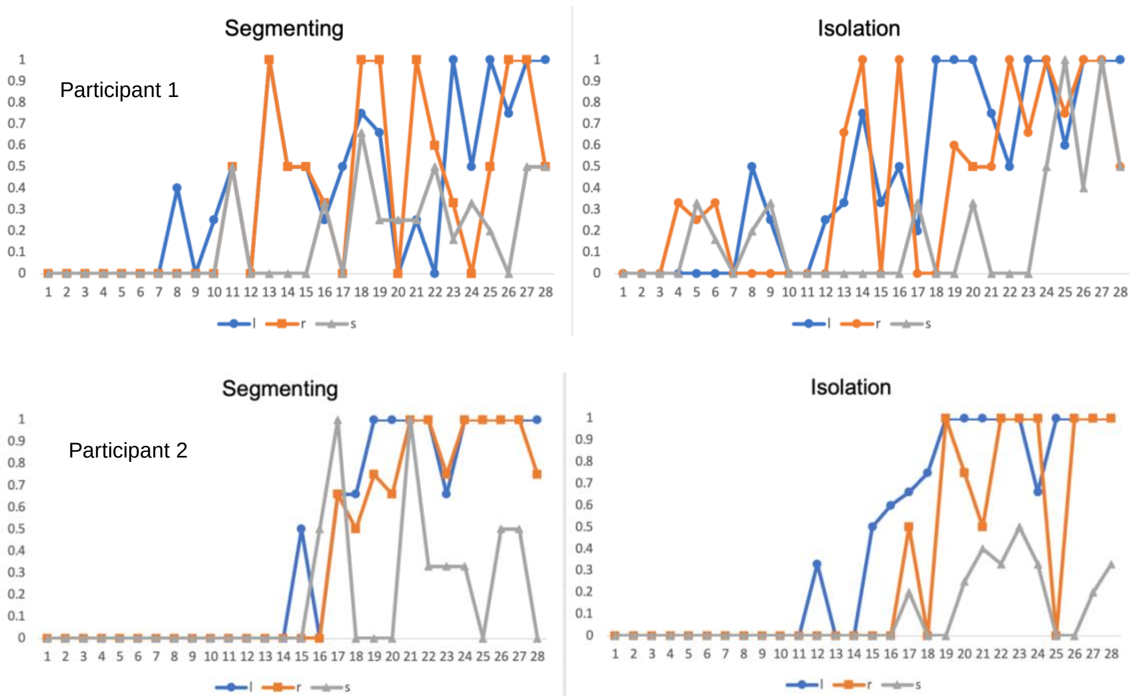


Figure 3.6 Proportion of Correct Responses by Word Blend

CHAPTER 4

DISCUSSION

The purpose of these studies was to evaluate the additive effects of the auditory benefit of an FM system on an evidence-based phonological awareness intervention for first grade students at risk for dyslexia. Part 1 of this study was completed in a classroom setting with the intervention delivered by the participants' teacher in a small group. Participants wore the FM system during lessons targeting one phonological awareness skill and did not use an FM during lessons targeting a different phonological awareness skill. In Part 2 of this study, participants completed a one-on-one phonological awareness intervention delivered by the author. Participants had simulated background noise play at a signal-to-noise ratio consistent with a classroom listening environment during lessons targeting one phonological awareness skill and at a signal-to-noise ratio consistent with the auditory benefit of an FM system in a classroom during lessons targeting a different phonological awareness activity.

In Study 1, it was hypothesized that participants would make faster growth and maintain those gains on the skill they were taught in conjunction with the FM system. Two of the four participants demonstrated quicker and greater growth for the skills learned in conjunction with the FM system. Two participants did not demonstrate growth in either skill. In Study 2, it was hypothesized that 1) participants would make progress from a phonological awareness intervention delivered via teletherapy and 2) participants would make faster growth on the skill learned during the low background noise condition compared to the high background noise condition. Two of the three participants made progress on phonological awareness skills targeted via teletherapy. However, a difference between skills learned in the low and high background noise conditions was not observed.

Study 1

In Study 1, Participants 1 and 2 achieved faster, consistent growth on the skill learned in conjunction with the FM system, even though the skill targeted with the FM was different for each participant. Participant 1 wore the FM during isolation lessons and Participant 2 wore it for segmenting lessons. Greater gains were evidenced on the skills targeted with the FM for these participants, independent of phonological awareness task, compared to performance on the skills targeted without the FM system. The other two participants in this study did not demonstrate growth in any of the three skill areas. Therefore, use of an FM system was associated with more rapid and lasting skill development on phonological awareness skills for those students who demonstrated improvement during the intervention.

Three skills were assessed during each progress monitoring assessment even though only two skills were targeted in intervention. The third skill, deletion was included in order to evaluate effects of generalization. Three of the four participants, Participant 2 and the two participants who did not make gains throughout the intervention, did not show any progress on deletion, with accuracy remaining around 10% or below. Participant 1 achieved a higher level of accuracy on deletion, but this remained around 40% throughout the intervention and did not reach the levels of the phonological awareness skills taught. Taken together, these findings suggest that there was little generalization between skills. This suggests that the skills are acquired independently of each other and that differences in performance were related to the use of FM system.

According to the phonological deficit model of dyslexia, impairments related to phonological representations of speech sounds lead to difficulties developing phonological awareness skills (Snowling, 1998). Researchers have further argued that auditory deficits play a causal role in the difficulties developing phonological representations. The findings reported here suggest that the provision of FM systems can be successful in mitigating the breakdown of auditory information processing experienced by children at risk for dyslexia during phonological awareness intervention.

The increased auditory benefit provided by the FM system was beneficial during instruction targeting the auditory-based skill of phonological awareness for children who responded to intervention. This finding is consistent with the literature on classroom noise. Classroom noise is inconsistent with standards set forth by professional associations (ASHA, 2005; ANSI, 2010). Furthermore, the noise in classrooms does not meet recommendations for optimal listening for children with typical development (Picard & Bradley, 2001). The impact of noise on academic performance and well-being for children with typical developmental and teachers alike is well documented (Evans & Lepore, 1993; Hétu et al., 1990). Additionally, previous research has found a link between noise in the classroom and reading performance (Lundquist et al., 2000; Shield & Dockrell, 2008). Furthermore, Shield and Dockrell (2008) reported that for children with special education needs, classroom noise has a particularly negative impact on academic performance. The findings from the current study confirm previous findings linking classroom noise to poorer performance in reading and provide evidence for appropriate accommodations. For children with special education needs related to reading impairment, the largest group of children receiving special education services in the US, an FM system provides a way to ameliorate the negative impact of internal and external classroom noise during classroom instruction.

Previous work had shown that using an FM system for an entire school day over the course of a school year resulted in increased phonological awareness performance (Hornickel et al., 2012). The findings from the current study suggest that FM systems need not be utilized for an entire school day or months to a year at a time in order to be effective and may be an effective tool for use in the short-term during auditory-based tasks. An effect was apparent within the intervention time period of only four weeks. Additionally, this study extends the current body of knowledge on the use of FM systems for populations with diagnoses other than hearing loss.

The findings from this current study extend findings from previous research that phonological awareness intervention is effective for children with reading impairments (Al Otaiba et al., 2009; Ehri et al. 2001; Suggate, 2010). Furthermore, this study also extends findings specifically related to the IPAP (Schuele & Murphy, 2014). The IPAP was previously used successfully in small-group kindergarten intervention with children at risk for reading disabilities (Schuele et al., 2008) and preschool children with hearing loss (Werfel & Schuele, 2014; Werfel et al., 2016). The findings of this current study illustrate the effectiveness of structured small group phonological awareness training programs such as the IPAP for children with phonological-based deficits.

As with other research-based interventions, not all participants made progress. For those participants who did make gains, progress was apparent after an average of five intervention sessions, four for Participant 1 and six for Participant 2. Two of the four did not make gains on any of the skills assessed, suggesting they are non-responders to best practice intervention. In fact, the intervention was based on recommended best-practices from the meta-study by the NRP (2000). For students that will eventually be non-responsive to intervention, time is of utmost importance when deciding whether to stay the course on a training program or pivot to a different method if no progress is being made. It may be useful for teachers and clinicians to attempt a different approach or ensure foundational skills are not absent that may be preventing progress. FM systems may be a powerful tool to expedite response to intervention of phonological awareness training.

Study Limitations

Due to school closures related to COVID-19, the children in this study were not able to participate in a maintenance condition after the intervention. The stability of their skill acquisition after the intervention ended was therefore unable to be assessed. Nonetheless, we were able to detect mastery of phonological awareness skills during this shortened intervention phase. Additionally, this study took place in a school for children with reading impairments. The children enrolled in first grade at this school may be representative of only a small subset of children with more severe reading impairments. The children in this study had reading impairments so severe that by first grade, they were enrolled in a school specifically for students with reading difficulties; reading impairments are often not diagnosed this early. Future work should explore the use of FMs with children with less severe reading impairments in general education settings.

Another limitation of the study is the classroom itself. Intervention occurred within a small group of four students. A typical classroom in a public school may have upwards of 25 to 30 students. The competing classroom noise was likely lower than it would be in more populous classrooms. Furthermore, the room in which the intervention occurred did not have windows and the school was not located directly on a high-traffic road or in an urban setting. Different indoor or outdoor conditions, such as more children in the classroom, a larger overall student body, more windows, classroom location next to the playground, or school location on a high traffic street would cause increased external and internal classroom noise. In these environments with louder background noise, FM systems may provide a greater auditory benefit than was observed in the current study. However, it is worth noting that as reported in Gremp and Easterbrooks (2018), even unoccupied classrooms utilized for specialized education do not meet the recommended noise guidelines. Therefore, it is not surprising that even in a small classroom with a small number of students, the use of an FM system provided auditory benefit during a phonological awareness intervention.

This study required a high amount of teacher involvement, effort, and little room for error. This study consisted of a classroom-based intervention with a teacher administering the intervention and teachers completing progress monitoring assessments. Additionally, there was a physical manipulative in the form of the FM systems which had to be correctly placed on students during intervention sessions and safely stored during the school day. It is essential to acknowledge the time commitment required of the teachers for their students to take part in this intervention. Future studies should continue to investigate the efficacy and feasibility of FM systems by using them in the school setting and assessing their use by school-based professionals in order to emulate typical instead of ideal usage.

Clinical Implications

This study suggests that the efficacy of FM systems extends beyond that for individuals with hearing loss alone. The participants in this study all passed a hearing screening and had no history of hearing difficulties. Even so, increasing the auditory access of the teacher's voice to these students at risk for dyslexia through the use of an FM system led to increased accuracy and quicker learning on the phonological awareness skill targeted while wearing the assisted listening devices. Acquisition of phonological awareness skills requires analyzing and manipulating sounds in words. This fine-tuned analysis of phonemes may be facilitated by the use of an FM system. Teachers and clinicians who work with individuals with reading impairments should consider the detrimental effects of background noise. Future research may recommend using FM systems to in the classroom for students with dyslexia.

Study 1 Conclusions

Study 1 evaluated the additive effects of FM system use on phonological awareness intervention for children at risk for dyslexia. Two out of four children showed greater progress on skills learned while using the FM system. The remaining two children did not demonstrate progress on any of the three skills assessed during the study. For those who did make progress, use of the FM resulted in quicker, greater gains than phonological awareness intervention alone. Notably, the greater and quicker gains of each participant were made across two different skills. For the children who did not make progress, no gains were seen across any of the three skills assessed. These findings suggest that FM systems show promise as a tool to be used during phonological awareness training for children at risk for dyslexia. Furthermore, this study suggests that there remain students who do not make progress following phonological awareness intervention even with the auditory benefit of an FM system.

Study 2

Study 2 investigated the use of teletherapy for an evidence-based phonological awareness intervention utilized in Study 1. Skills were either presented in a low background noise or high background noise condition. Each participant learned one skill in each condition, the conditions were randomized between participants. Three participants participated in this virtual intervention study. Two of the participants made gains on phonological awareness measures throughout the study.

Participant 1 demonstrated more consistent growth on isolation, the task learned in the low background noise condition based on visual analysis. He also demonstrated growth on segmenting, the task learned in the high background noise condition. Additionally, Tau-U analysis revealed moderate to very large effect sizes for both skills taught during the intervention from baseline to intervention. Participant 2 exhibited a consistent upward trend on isolation than segmenting during the intervention phase, however, this trend did not continue into the maintenance phase. Participant 2 showed increased accuracy on the skills targeted in the intervention compared to the skill assessed but not targeted. However, no difference between the skill targeted in the low background noise condition and the skill targeted in the high background noise condition was observed. Participant 3 did not make gains throughout the intervention or maintenance conditions, showing no meaningful improvement on any skill assessed. This finding was supported by Tau-U effect sizes.

Research Question 1: Telepractice for Phonological Awareness Training

Two of the participants made progress on the phonological awareness sills targeted during the phonological awareness program conducted via telepractice. This finding suggests teletherapy shows promise as a method of delivery for phonological awareness intervention. The current study corroborates previous research findings that teletherapy is an effective method of treating and assessing speech-language targets, including those requiring fine-tuned auditory analysis

(Coufal et al, 2018; Jessiman, 2003; Lee, 2018; Pullins & Grogan-Johnson, 2017; Werfel et al., in press). Lee and colleagues (2017) reported in particular that phonological awareness intervention delivered via teletherapy resulted in similar outcomes to intervention delivered in-person; which is in line with the results from this current study.

Research Question 2: Effect of Low Background Noise Condition

The second research question investigated whether there was an effect for skills learned during an intervention with a simulated classroom FM system compared to those learned during an intervention with simulated classroom noise. Progress was evident for two of the participants even with simulated classroom background noise; however, there was not an appreciable difference between skills learned in the condition that simulated a typical classroom and those learned in the condition that simulated a classroom with the auditory benefit of an FM. Although this study demonstrated the effectiveness of virtual sound-based intervention, clear differences did not emerge between the low and high background noise conditions.

There are several potential explanations for this outcome. This result may be due to a circumstance surrounding the noise itself. The locus of sound emitting only from one source, the computer speakers, may have failed to adequately simulate the enveloping background noise of an authentic classroom. As noted in the literature, classroom background noise does not merely have one source (see a review by Shield & Dockrell, 2003). There are multiple external sources, such as street noise, air traffic, and children in the playground or hallway, in addition to internal noises, such as children talking, air conditioners, and support personnel. Although the simulated background noise included two sources (hallway crowd and HVAC system), modeling the spatialized locations of these different sources is not possible via a single computer speaker. Additionally, both the speaker's voice and background noise were emitting from the same computer speaker, in a classroom, each of these noises would be coming from a distinct sound source. The simulated background noise did not simulate reverberation. This is another aspect of classroom noise that is not able to be represented in sound emitting from a computer speaker, and reverberation may be particularly implicated in degraded auditory signals in classrooms (Klattle et al., 2010). Conversely, this finding may be explained by another aspect that differed between the studies. One such explanation is the provision of training individually versus in a group. Although even unoccupied classrooms surpass recommended auditory standards (Spratford et al., 2019), a major source of noise in classrooms is the other students. Therefore, the provision of this intervention individually and not in groups may have obviated the need for FM systems, even with simulated classroom noise. On the other hand, a group setting provides additional stimuli and input. The incorrect and correct responses of peers provide valuable learning opportunities for the students. The repetition of peers answering questions and completing activities also provides multiple opportunities to review the material without the interventionist or single student supplying all of the information. All of these may facilitate understanding.

Another difference between virtual and in person intervention that could explain the lack of effect between the low and high background noise conditions is the setting. In a classroom, the physical environment and other children are all supporting or attending to the same lesson. In a virtual training program, the intervention extends only as far as the computer. There may be competing stimuli, such as siblings playing in another room, someone in the kitchen, or nearby playthings that affect a student's ability to attend to a virtual lesson in ways that are different from in-person distractions. Some of these distractions in the home environment, or the participant's inability to tune them out, may in part explain the lack of effect between the conditions.

Conclusions of Study 2

Teletherapy shows promise as a method of delivery for phonological awareness instruction and assessment. However, a benefit of the low background noise condition, which simulated the signal-to-noise ratio of a classroom-based FM system over the high background noise condition, which simulated the background noise found in a classroom did not emerge. Participants acquired skills learned in either condition in a similar amount of time. Aspects related to the background noise itself or more broadly, aspects of the training program may be responsible for this finding.

Comparison of Findings in Study 1 and Study

Similarities were present among the performance of participants across studies. Participants 1 and 2 in Study 1 and 2 made gains on the skills targeted in the intervention. In Study 1, participants made gains within four or six sessions. In Study 2, Participant 1 made gains in six sessions, similar to those in the in-person intervention. However, for Participant 2, gains were not evident until session ten.

Although both modes were eventually effective, perhaps in-person phonological awareness intervention is associated with faster response.

Conversely, Participants 3 and 4 in Study 1 and Participant 3 in Study 2 did not make gains on any of the skills targeted in the intervention. This suggests that for some children, a 6-week, 90 minute per week intervention targeting phonological awareness skills is insufficient. This was true across both modes of intervention delivery. As discussed in the literature, non-responders to best-practice intervention exist and consist of a substantial proportion of students with reading impairments (Al Otaiba & Fuchs, 2002). For these students, progress on phonological awareness training may not emerge eve with the additive use of an FM system.

Differences were not present in Study 2 between skills learned in the low background noise or high background noise condition. In Study 2, the signal-to-noise ratio of FM systems was simulated. This finding from Study 2 would suggest that perhaps it is not the signal-to-noise ratio, but another aspect of the auditory benefit of FM system that was responsible for faster acquisition of skills in Study 1 and improved academic performance and listening behaviors in children with dyslexia (Hornickel et al., 2012; Purdy et al., 2009). This study suggests that another aspect besides or in addition to the increased signal-to-noise ratio contributes to the classroom benefit of an FM system for children with reading impairments.

However, there are several differences between Study 1 and Study 2 related to both the sound and other aspects of the intervention. Study 2 simulated the signal-to-noise ratio of a classroom-based FM system. Of note, in this instance the background noise was increased or decreased to obtain the target signal-to-noise, instead of the speaker's voice being amplified above the background noise as is done in an FM system. Other aspects of the FM that were not simulated in Study 2 include reverberation and the different sound source for the speaker's voice. It is also important to consider that attention or listening effort may be a mediating factor. The FM system may decrease listening effort needed or increase attention and this in turn may be responsible for increases in classroom performance. Ultimately, although the findings from this study suggest the FM system was associated with faster and greater acquisition of phonological awareness skills, it is not able to explain precisely what about the FM system accounts for the expedited skill development, but it appears factors beyond signal-to-noise ratio are involved.

Another important difference between the studies was related to the participants. The children that were tested for Study 2 exhibited greater skill variability across literacy and language measures than the participants for Study 1. A relatively high proportion of children whose parents were actively seeking reading intervention through social media completed eligibility testing but were found to be ineligible for Study 2. One child demonstrated vocabulary weaknesses. Sufficient semantic knowledge of vocabulary used, as stated in Werfel and Reynolds (2019), is essential for effective phonological awareness intervention. Four of the children screened for Study 2 scored above average on the Phonological Awareness Composite of the CTOPP; two scored in the 98th

percentile. For these children, although their parents had identified reading as an area of weakness, foundational skills such as phonological awareness were not necessarily a source of difficulty. Conversely, the participants for Study 1 were attending a specialized school for dyslexia. The reading impairments of the students in Study 1 were severe enough for them to be enrolled in a school for children with dyslexia by first grade. In Study 2, parents were concerned about their child’s reading but were not required to have identified which aspects of literacy their child struggled with.

Furthermore, unlike in Study 1, hearing was not assessed. The presence of hearing loss, as was reported by Werfel and colleagues (2020) to be common among children with reading impairments, cannot be ruled out as a cause of reading difficulty. It is therefore important to consider that the learning and literacy profiles of the groups of children may differ from Study 1 to Study 2. It is likely that the profiles of children in Study 1 are more similar to each other than the children in Study 2. It is also probable that those presenting with differing language and literacy profiles responded differently to the intervention.

Future research should continue to investigate the effectiveness of FM systems in the classroom for children with dyslexia and other reading impairments, specifically during reading intervention. The use of FM systems for children with reading impairment in the general education setting should be explored. In particular, phonological awareness training, which requires attention to small units of sounds, presents a promising domain for the use of assistive hearing technology. Studies should be conducted to investigate the response to FM systems across different populations of children with reading impairment. Their effectiveness may vary based on the presence or absence of minimal hearing loss, more pervasive phonological awareness deficits, or other aspects related to learning and literacy profiles. This information may also inform the mechanism by which an FM system improves academic performance in children with reading impairments. Additionally, future work should continue to explore the use of FM systems for relatively short increments of time (6 weeks compared to a school year or 30 minutes a day compared to a whole school day). Additional research may also be warranted to investigate the delivery of phonological awareness treatment via telepractice and provide recommendations for best practices.

Comparison of Blend Words in Progress Monitoring Assessment Across Studies

For Study 1 participants, differences in accuracy were not observed between sounds that were targeted in the intervention, /l/ and /r/ blend words, and those that were not, /s/ blend words, on the daily progress monitoring assessment. However, Study 2 participants achieved higher accuracy on /l/ and /r/ blend words than /s/ blend words. Furthermore, this higher accuracy was achieved in fewer sessions than mastery of /s/ blend words. In fact, even by the end of the study, which continued after the intervention had ended to assess skill maintenance, performance on /s/ blend words for the participants in Study 2 did not approximate their performance on /l/ and /r/ blend words. Participant 2 had achieved ceiling performance on /l/ and /r/ blend words while performing below 50% accuracy on /s/ blend words in segmenting and isolation. These findings illustrate that participants in Study 2 did not generalize the phonological awareness skills to a sound blend they were not explicitly taught.

The findings from the present study indicate that the children in Study 2 struggled to generalize phonological awareness sounds to untaught sounds whereas the children in Study 1 were able to generalize across sounds. Several differences were present between Study 1 and Study 2 that could explain this difference. First, the instruction for Study 1 occurred in person whereas the instruction for Study 2 occurred virtually. Differences related to the virtual delivery of the intervention include the quality of the sound coming through the participant's speakers, a one-on-one as opposed to small group intervention, and participation from a home instead of classroom environment. Given the wide array of aspects that differ when instruction is delivered in a virtual format, it is likely that one or more of these contributed to the differences in generalization. However, other differences between the studies remain. The differences in generalization may also be due to differences in the participants between the studies. The participants in Study 1 were recruited from a school that specialized in children with dyslexia, whereas the participants in Study 2 were enrolled in general education settings. These two groups of participants may have had different underlying profiles that motivated their reading impairments and thus responded differently to the intervention. Additionally, the participants in Study 1 had normal hearing as determined by a hearing screening, whereas the participants in Study 2 did not have their hearing assessed.

In a study investigating sound segmentation in children with hearing loss, Werfel and Schuele (2014) found a similar finding regarding generalization. The children did not generalize sound segmenting skills to sounds that were not explicitly taught. In Werfel and Schuele's (2014) study, the hearing loss of the participants impacted their ability to generalize sound segmenting skills. Therefore, it would appear likely that the lack of generalization of Study 2 participants had at least one auditory-based cause. Of the differences between Study 1 and Study 2, auditory differences include the transmission of the intervention itself through a speaker instead of in person and the lack of hearing screenings for Study 2 participants to rule out hearing loss. The degraded sound quality of the intervention as it was transmitted into the microphone and through the speakers of the participants' computers or an underlying minimal hearing loss of Study 2 participants may explain the similar performance of these children with reading impairment to children with hearing loss.

Limitations

Several limitations were present in Study 2. As previously mentioned, the signal-to-noise ratio of a classroom-based FM system, but not other aspects of this technology, such as amplification of speaker's voice or isolation of the target sound source were simulated. Similarly, the volume of classroom background noise was simulated, but not the wide array of differing sources of classroom background noise. Additionally, in a physical FM system, the teacher's voice is amplified over the background noise. In Study 2, the background noise was adjusted while the volume of the speaker's voice remained constant. Furthermore, the intervention occurred one-on-one, instead of in small groups, which is the recommended size of instruction from both the NRP metastudy (2000) and the IPAP (Schuele & Murphy, 2014).

The method of participant recruitment may have led to differences in learning profiles and response to intervention across the two studies. In Study 1, the participants were recruited from the first grade classroom of a specialized school for students with dyslexia. In Study 2, participants were recruited from social media parent groups. None of the three participants that met eligibility criteria for Study 2 were enrolled in a specialized school; two attended public school and one was homeschooled. The participants in Study 1 struggled with reading to the extent that they were enrolled in a school to address their specific needs by first grade. This is notable because dyslexia is often not diagnosed this early. Additionally, the participants in Study 1 received a hearing screening and were found to all have typical hearing. However, the hearing acuity of Study 2 participants is not known as a hearing screening was not conducted virtually. Therefore, these participants may differ from each other in ways beyond the presentation of the intervention. However, this is not a problem in single case design as the participants are compared to themselves.

Future studies should continue to investigate the use of FM systems during literacy, and particularly phonological awareness, intervention for students with reading impairment, particularly for shorter periods of time than an entire school day, as the only previous two studies on FM system use for children with dyslexia have done (Hornickel et al., 20012; Purdy et al., 2009). Additionally, more information is needed on the response of different learning profiles of students to FM systems. The students enrolled in specialized schools for children with reading impairment may respond differently to FM systems than children with reading impairment in a general education setting. Furthermore, specialized schools often have resources and vested interest in working with researchers; students from these schools appear prominently in the FM system literature (Hornickel et al., 2012; Schafer et al., 2013). Research into a wide array of subtypes of students with reading impairment is needed.

Finally, future research should continue to investigate the generalization of sound-based skills of children with reading impairment via telehealth. Specifically to determine if the findings of the current study replicate, and to determine its specific cause, whether the lack of generalization is related to unassessed hearing acuity, the degraded auditory output of the speakers, or some other aspect of telepractice.

Clinical Implications

Virtual delivery of phonological awareness intervention shows promise as an effective method of transmission. However, the lack of generalization on sounds not taught in Study 2 suggest a potential limitation of virtual intervention. The lack of generalization of the two participants who made progress in Study 2 suggests that there may be subtle differences between virtual and in-person phonological awareness intervention. The differences may impact acquisition and generalization of skills and may need to be considered when conducting virtual assessment or intervention of sound-based skills. Future research should investigate these differences, specifically the generalization of auditory-based skills to sounds that were not taught in virtual intervention.

Additionally, although FM systems were associated with faster and more consistent skill attainment in Study 1, the cause of the benefit remains unknown. The simulated signal-to-noise ratio of Study 2 did not result in differences in skill acquisition. However, other differences between the benefit provided by the FM system and the simulated benefit of the FM system remain, such as lack of reverberation time, single locus of speaker voice and background noise, and simulation of all background noise emitting from one speaker. Future research should investigate the mechanism of enhancement of academic performance associated with use of FM systems. Additionally, future research should explore the response of different learning profiles of students (severe dyslexia, reading impairment secondary to a minimal hearing loss, reading impairment and ADHD, etc.) to FM systems to determine if their use is more beneficial for only a subset of students with reading impairment.

Overall Conclusions

First-grade children at risk for dyslexia participated in a phonological awareness intervention in one of two settings. Participants in Study 1 received in-person intervention in the classroom in small groups and used an FM system during lessons targeting one of the skills. Participants in Study 2 participated in the intervention remotely; lessons targeting one skill were accompanied by background noise simulated to imitate the signal-to-noise ration of a classroom environment and lessons targeting the other skill were accompanied by background noise simulated to imitate the signal-to-noise ratio of a classroom-based FM system. The pairing of skill and condition was randomized for each participant for Study 1 and Study 2.

Two of the four participants in Study 1 made progress on the skills targeted in the phonological awareness training program. Both participants made faster and more consistent gains on the skill learned while they were wearing the FM system, which was a different skill for each participant. The other 2 participants did not make gains in either of the skills taught. In Study 2, two of the three participants made progress on the skills targeted in the phonological awareness training program. However, differences did not emerge between skills learned in the low background noise and high background noise condition.

Findings from Study 1 suggest that FM systems are associated with faster and more consistent growth for those students who will make progress during a phonological awareness intervention. Study 2 indicates that participants make progress on phonological awareness skills from a phonological awareness training delivered remotely. Additionally, participants in Study 2 did not demonstrate differences across conditions. An aspect of the noise simulation or the overall intervention itself may explain this result.

Study 1 suggests that the use of FM systems during phonological awareness training specifically and reading instruction broadly may be associated with more expedient gains. Study 2 suggests telehealth shows progress as an effective method of delivery for phonological awareness training and assessment. Additionally, although FM systems were associated with faster and more consistent skill attainment in Study 1, the cause of the benefit remains unknown. The simulated signal-to-noise ratio of Study 2 did not result in differences in skill acquisition. However, other differences between the benefit provided by the FM system and the simulated benefit of the FM system remain, such as lack of reverberation time, single locus of speaker voice and background noise, and simulation of all background noise emitting from one speaker. Future research should investigate the mechanism of enhancement of academic performance associated with use of FM systems. Additionally, future research should explore the response of different learning profiles of students (severe dyslexia, reading impairment secondary to a minimal hearing loss, reading impairment and ADHD, etc.) to FM systems to determine if their use is more beneficial for only a subset of students with reading impairment.

REFERENCES

Adams, M. (1990). *Beginning to read: Thinking and learning about print.* Cambridge, MA: MIT Press.

Al Otaiba, S & Fuchs, D. (2002). Characteristics of children who are unresponsive to early literacy intervention: A review of the literature. Remedial and Special education, 23(5), 300-316. doi: 1 0 .1177/07419325020230050501

Alt, M., Hogan, T., Green, S., Gray, S., Cabbage, K., & Cowan, N. (2017). Word learning deficits in children with dyslexia. *Journal of Speech, Language, and Hearing Research, 60*(4), 1012-1028.

American Academy of Audiology. (2011). *American Academy of Audiology Clinical Practice Guidelines: Childhood Hearing Screen*. Reston, VA: American Academy of Audiology.

American Speech-Language-Hearing Association. (1995). Childhood hearing screen.https://www.asha.org/PRPSpecificTopic.aspx ?folderid=8589935406& section=Key_Issues

American Speech-Language-Hearing Association (n.d.). *Classroom Acoustics* (Practice Portal). Retrieved March, 18, 2021, from www.asha.org/Practice-Portal/Professional-Issues/Classroom-Acoustics/.

Anthony, J. L., & Francis, D. J. (2005). Development of phonological awareness. *Current directions in psychological Science*, *14*(5), 255-259.

Anthony, J. L, Lonigan, C. J., Driscoll, K., Phillips, B. M., & Burgess, S. R. (2003). Phonological sensitivity: A quasi-parallel progression of word structure units and cognitive operations. *Reading Research Quarterly, 38*, 470-487.

Bess, F., Dodd-Murphy, J., & Parker, R. (1998). Children with minimal sensorineural hearing loss: Prevalence, educational performance, and functional status. *Ear & Hearing, 19*, 339-354.

Bess, F. H., Tharpe, A. M., & Gibler, A. M. (1986). Auditory performance of children with unilateral sensorineural hearing loss. *Ear and hearing,* 7(1), 20-26.

Berglund, B., & Lindvall, T. (1995). *Community noise*: Center for Sensory Research, Stockholm University and Karolinska Institute

Blachman, B.A., Ball, E.W., Black, R.S., & Tangel, D.M. (1994). Kindergarten teachers develop phoneme awareness in low-income, inner-city classrooms. *Reading and Writing*, *6*(1), 1-18.

Boada, R., & Pennington, B.F. (2006). Deficient implicit phonological representations in children with dyslexia. *Journal of Experimental Child Psychology, 95*(3), 153-193. doi:https://doi.org/10.1016/j.jecp.2006.04.003

Boets, B., de Beeck, H.P.O., Vandermosten, M., Scott, S.K., Gillebert, C.R., Mantini, D., ... & Ghesquière, P. (2013). Intact but less accessible phonetic representations in adults with dyslexia. *Science*, *342*(6163), 1251-1254.

Brown, L., Sherbenou, R.J., & Johnsen, S.K. (2010) *Test of Nonverbal Intelligence- 4th ed. (TONI-4).* Austin TX: Pro-ed.

Calfee, R. C., Lindamood, P., & Lindamood, C. (1973). Acoustic-phonetic skills and reading: Kindergarten through twelfth grade. *Journal of Educational Psychology*, *64*(3), 293. doi:10.1037/h0034586

Carroll, J., & Breadmore, H. (2018). Not all phonological awareness deficits are created equal: Evidence from a comparison between children with otitis media and poor readers. *Developmental Science, 21(3),* 1-12. doi: 10.1111/desc.12588

Casini, L., Pech-Georgel, C., & Ziegler, J.C. (2018). It's about time: revisiting temporal processing deficits in dyslexia. *Developmental Science, 21*(2), e12530. doi:https://doi.org/10.1111/desc.12530

Catts, H.W., Adlof, S.M., Hogan, T.P., & Weismer, S.E. (2005). Are specific language impairment and dyslexia distinct disorders?. *Journal of Speech, Language, and Hearing Research*.

Catts, H.W., Fey, M.E., Zhang, X., & Tomblin, J.B. (2001). Estimating the risk of future reading difficulties in kindergarten children. *Language, speech, and hearing services in schools*. doi: 10.1044/0161-1461(2001/004)

Cohn, E. R., & Cason, J. (2012). Telepractice: A Wide-Angle View for Persons with Hearing Loss. *Volta Review*, *112*(3).

Coles, G. (1998). Reading lessons :The debate over literacy. New York: Hill and Wang

Coufal, K., Parham, D., Jakubowitz, M., Howell, C., & Reyes, J. (2018). Comparing traditional service delivery and telepractice for speech sound production using a functional outcome measure. American Journal of Speech-Language Pathology, 27(1), 82-90.

Crandell, C. C. (1993). Speech recognition in noise by children with minimal degrees of sensorineural hearing loss. *Ear and hearing*, 14(3), 210-216.

Culbertson, J. L., & Gilbert, L. E. (1986). Children with unilateral sensorineural hearing loss: cognitive, academic, and social development. *Ear and hearing,* 7(1), 38-42.

Dawson, J. I., Stout, C. E., & Eyer, J. A. (2003). *SPELT-3: Structured Photographic Expressive Language Test–Third Edition*. Dekalb, IL: Janelle Publications.

de Gelder, B., & Vroomen, J. (1991). Phonological deficits: Beneath the surface of reading-acquisition problems. *Psychological research*, *53*(1), 88-97.

Dockrell, J. E., & Shield, B. M. (2006). Acoustical barriers in classrooms: The impact of noise on performance in the classroom. *British Educational Research Journal*, *32*(3), 509-525. doi: 10.1080/01411920600635494

Fairweather, G.C., Lincoln, M.A., & Ramsden, R. (2016). Speech-language pathology teletherapy in rural and remote educational settings: Decreasing service inequities. International journal of speech-language pathology, 18(6), 592-602.

Finitzo-Hieber, T., & Tillman, T.W. (1978). Room acoustics effects on monosyllabic word discrimination ability for normal and hearing-impaired children. *Journal of speech and hearing research,* 21(3), 440-458. doi: 10.1044/jshr.2103.440

Friederichs, E., & Friederichs, P. (2005). Electrophysiologic and psycho-acoustic findings following one-year application of a personal ear-level FM device in children with attention deficit and suspected central auditory processing disorder. *Journal of Educational Audiology*, *12*, 31-36.

Fudala, J.B., & Stegall, S. (2017). *Arizona Articulation and Phonology Scale–Fourth Edition* (Arizona-4). Torrance, CA: Western Psychological Services.

Gaba, D.M., & Howard, S.K. (2002). Fatigue among clinicians and the safety of patients. *New England Journal of Medicine*, 347(16), 1249-1255.

Goswami, U. (2000). Phonological representations, reading development and dyslexia: Towards a cross-linguistic theoretical framework. *Dyslexia*, 6(2), 133-151. doi: 10.1002/(SICI)1099-0909(200004/06)6:2<133::AID-DYS160>3.0.CO;2-A

Goswami, U. (2015). Sensory theories of developmental dyslexia: three challenges for research. *Nature Reviews Neuroscience, 16*(1), 43-54.

Gough, P.B., & Tunmer, W.E. (1986). Decoding, reading, and reading disability. *Remedial and special education*, *7*(1), 6-10. doi: 10.1177/074193258600700104

Gremp, M.A., & Easterbrooks, S.R. (2018). A descriptive analysis of noise in classrooms across the US and Canada for children who are deaf and hard of hearing. The Volta Review, 117(1-2), 5-31.

Gustafson, S.J., Key, A.P., Hornsby, B.W., & Bess, F.H. (2018). Fatigue related to speech processing in children with hearing loss: behavioral, subjective, and electrophysiological measures. *Journal of Speech, Language, and Hearing Research*, *61*(4), 1000-1011.

Hartvig Jensen, J., Johansen, P.A., & Børre, S. (1989). Unilateral sensorineural hearing loss in children and auditory performance with respect to right/left ear differences. *British journal of audiology*, *23*(3), 207-213.

Hawkins, D.B. (1984). Comparisons of speech recognition in noise by mildly-to-moderately hearing-impaired children using hearing aids and FM systems. *Journal of Speech and Hearing Disorders, 49*(4), 409-418.

Hétu, R., Truchon-Gagnon, C., & Bilodeau, S.A. (1990). Problems of noise in school settings: A review of literature and the results of an exploratory study. *Journal of Speech-Language Pathology and Audiology*.

Hogan, T.P., Catts, H.W., & Little, T.D. (2005). The Relationship Between Phonological Awareness and Reading. *Language, Speech, and Hearing Services in Schools, 36*(4), 285-293. doi:doi:10.1044/0161-1461(2005/029)

Hornickel, J., Zecker, S., Bradlow, A., & Kraus, N. (2012). Assistive listening devices drive neuroplasticity in children with dyslexia. *PNAS, 109,* 16731-16736. doi:10.1073/pnas.1206628109

Hornsby, B.W., Werfel, K., Camarata, S., & Bess, F.H. (2014). Subjective fatigue in children with hearing loss: Some preliminary findings. *American Journal of Audiology.*

Horwitz, B., Rumsey, J.M., & Donohue, B.C. (1998). Functional connectivity of the angular gyrus in normal reading and dyslexia. *Proceedings of the National Academy of Sciences*, *95*(15), 8939-8944.

Hulme, C., Hatcher, P. J., Nation, K., Brown, A., Adams, J., & Stuart, G. (2002). Phoneme awareness is a better predictor of early reading skill than onset-rime awareness. *Journal of experimental child psychology*, 82(1), 2-28.

Hulme, C., Bowyer-Crane, C., Carroll, J.M., Duff, F.J., & Snowling, M.J. (2012). The causal role of phoneme awareness and letter-sound knowledge in learning to read: Combining intervention studies with mediation analyses. *Psychological science*, 23(6), 572-577.

Jessiman, S. (2002). Speech and language services using telehealth technology in remote and underserviced areas. *Journal of Speech Language pathology and Audiology, 27*(1), 45-51.

Johnston, K. N., John, A. B., Kreisman, N. V., Hall III, J. W., Crandell, C. C.,(2009). Multiple benefits of personal FM system use by children with auditory processing disorder (APD). *International journal of audiology*, *48*(6), 371-383. doi: 10.1080/14992020802687516

Kamhi, A. G., & Catts, H. W. (1986). Toward an understanding of developmental language and reading disorders. *Journal of Speech and Hearing Disorders*, *51*(4), 337-347.

Klatte, M., Lachmann, T., & Meis, M. (2010). Effects of noise and reverberation on speech perception and listening comprehension of children and adults in a classroom-like setting. Noise and Health, 12(49), 270.

Kratochwill, T. R., Hitchcock, J., Horner, R. H., Levin, J. R., Odom, S. L., Rindskopf, D. M. & Shadish, W. R. (2010). Single-case designs technical documentation. Retrieved from What Works Clearinghouse website: http://ies.ed.gov/ncee/wwc/pdf/wwc_scd.pdf.

Lee, S.A.S., Hall, B., & Sancibrian, S. (2017). Feasibility of a supplemental phonological awareness intervention via telepractice for children with hearing loss: a preliminary study. *International journal of telerehabilitation*, *9*(1), 23.

Lee, S.A.S. (2018). The treatment efficacy of multiple opposition phonological approach via telepractice for two children with severe phonological disorders in rural areas of West Texas in the USA. Child Language Teaching and Therapy, 34(1), 63-78.

Lonigan, C.J., Burgess, S.R., Anthony, J. L., & Barker, T.A. (1998). Development of phonological sensitivity in 2- to 5-year-old children. *Journal of Educational Psychology, 90*, 294-311. doi: 10.1037/0022-0663.90.2.294

Lundquist, P., Holmberg, K., & Landstrom, U. (2000). Annoyance and effects on work from environmental noise at school. *Noise and Health, 2*(8), 39.

Lyon, G.R., Shaywitz, B., & Shaywitz, S. (2003). A definition of dyslexia. *Annals of Dyslexia*, 53, 1-14. doi: 10.1007/s11881-003-0001-9

Mattingly, I. G. (1972). *Reading, the linguistic process, and linguistic awareness.* In J. Kavanagh & I. Mattingly (Eds.), Language by ear and by eye: The relationships between speech and reading (pp. 133-147). Cambridge, MA: MIT Press.

Maxwell, L. E., & Evans, G. W. (2000). The effects of noise on pre-school children's pre-reading skills. *Journal of environmental Psychology, 20*(1), 91-97.

Meinke, D.K., & Dice, N. (2007). Comparison of audiometric screening criteria for the identification of noise-induced hearing loss in adolescents. *American Journal of Audiology*.

Metsala, J.L. (1997). Spoken word recognition in reading disabled children. *Journal of Educational Psychology*, *89*(1), 159.

Melby-Lervåg, M., Lyster, S.A.H., & Hulme, C. (2012). Phonological skills and their role in learning to read: a meta-analytic review. Psychological bulletin, 138(2), 322.

Moeller, M.P., Tomblin, J. B., Yoshinaga-Itano, C., Connor, C.M., & Jerger, S. (2007). Current state of knowledge: Language and literacy of children with hearing impairment. *Ear and hearing*, *28*(6), 740-753.

Most, T. (2004). The effects of degree and type of hearing loss on children's performance in class. Deafness & Education International, 6(3), 154-166.

Most, T. (2006). Assessment of school functioning among Israeli Arab children with hearing loss in the primary grades. American annals of the deaf, 151(3), 327- 335.

Nabelek, A. K., & Pickett, J. M. (1974). Monaural and binaural speech perception through hearing aids under noise and reverberation with normal and hearing-impaired listeners. *Journal of Speech and Hearing Research*, *17*(4), 724-739.

Nachtegaal, J., Kuik, D.J., Anema, J.R., Goverts, S.T., Festen, J. M., & Kramer, S.E. (2009). Hearing status, need for recovery after work, and psychosocial work characteristics: Results from an internet-based national survey on hearing. *International journal of audiology*, 48(10), 684- 691.

National Institute of Child Health and Development (2007). Learning disabilities: What are learning disabilities?

National Reading Panel. (2000). *Teaching children to read: An evidence-based assessment of the scientific research literature on reading and its implications for reading instruction.* Washington, DC: U.S. National Institute for Literacy. https://www.nichd.nih.gov/sites/default/files/publications/pubs/nrp/Documents/ report.pdf

NCES. (2016). *Digest of Education Statistics, 2015 (NCES 2016-014), Chapter 2*. Washington, DC: US Department of Education. https://nces.ed.gov/pubs2016/2016014.pdf

Nittrouer, S. (1996). The relation between speech perception and phonemic awareness: Evidence from low-SES children and children with chronic OM. *Journal of Speech, Language, and Hearing Research*, *39*(5), 1059-1070.

Parker, R. I., Vannest, K. J., Davis, J. L., & Sauber, S. B. (2011). Combining nonoverlap and trend for single-case research: Tau-U. *Behavior Therapy*, *42*(2), 284-299. doi:10.1016/j.beth.2010.08.006

Picard, M., & Bradley, J. S. (2001). Revisiting Speech Interference in Classrooms. *Audiology*, *40*(5), 221-244. doi:10.3109/00206090109073117

Powell, D., & Atkinson, L. (2020). Unraveling the links between rapid automatized naming (RAN), phonological awareness, and reading. Journal of Educational Psychology.

Pullins, V., & Grogan-Johnson, S. (2017). A clinical decision making example: Implementing intensive speech sound intervention for school-age students through telepractice. Perspectives of the ASHA Special Interest Groups, 2(18), 15-26.

Purdy, S., Smart, J., Baily, M., & Sharma, M. (2009). Do children with reading delay benefit from the use of personal FM systems in the classroom? *International Journal of Audiology, 12,* 843-852. doi: 10.3109/14992020903140910

Quigley, S., & Thomure, R. (1968). Some effects of a hearing impairment on school performance. Ear Hear, 6, 43-47.

Rack, J. P., Snowling, M. J., & Olson, R. K. (1992). The nonword reading deficit in developmental dyslexia: A review. *Reading Research Quarterly*, 29-53.

Ramus, F. (2014). Neuroimaging sheds new light on the phonological deficit in dyslexia. *Trends in cognitive sciences, 18*(6), 274-275.

Ramus, F., & Szenkovits, G. (2008). What phonological deficit?. *Quarterly Journal of Experimental Psychology*, *61*(1), 129-141. doi: 10.1080/17470210701508822

Ramus, F., White, S., & Frith, U. (2006). Weighing the evidence between competing theories of dyslexia. *Developmental Science*, *9*(3), 265-269. doi: 10.1111/j.1467-7687.2006.00488.x

Rance, G., Saunders, K., Carew, P., Johansson, M., & Tan, J. (2014). The use of listening devices to ameliorate auditory deficit in children with autism. *The Journal of pediatrics*, *164*(2), 352-357. doi: 10.1016/j.jpeds.2013.09.041

Schafer, E. C., & Thibodeau, L. M. (2006). Speech Recognition in Noise in Children With Cochlear Implants While Listening in Bilateral, Bimodal, and FM-System Arrangements. *American Journal of Audiology, 15*(2), 114-126. doi:doi:10.1044/1059-0889(2006/015)

Schuele, M. & Murphy, N. (2014). The Intensive Phonological Awareness Program (IPA). Baltimore, MD: Brookes Publishing.

Schuele, C. M., Justice, L. M., Cabell, S. Q., Knighton, K., Kingery, B. and Lee, M. W. (2008). Field-based evaluation of two-tiered instruction for enhancing kindergarten phonological awareness. *Early Education and Development*, *19,* 726-752. doi:10.1080/10409280802375299

Shaywitz, S. E., & Shaywitz, B. A. (2005). Dyslexia (specific reading disability). *Biological psychiatry*, *57*(11), 1301-1309. doi: 10.1542/pir.24-5-147

Shield, B. M., & Dockrell, J. E. (2003). The effects of noise on children at school: A review. *Building Acoustics*, 10(2), 97-116.

Shield, B. M., & Dockrell, J. E. (2008). The effects of environmental and classroom noise on the academic attainments of primary school children. *The Journal of the Acoustical Society of America*, *123*(1), 133-144. doi: 10.1121/1.2812596

Short, L., Rea, T., Houston, B., Scott, S., & Forducey, P. (2016). Positive Outcomes for Speech Telepractice as Evidence for Reimbursement Policy Change. *Perspectives of the ASHA Special Interest Groups*, *1*(18), 3-11.

Sindelar, P.T., Rosenberg, M.S., & Wilson, R.J. (1985). An adapted alternating treatments design for instructional research. *Education and Treatment of Children*, 67-76. https://www.jstor.org/stable/42898888?seq=1

Snowling, M.J. (2001). From language to reading and dyslexia1. *Dyslexia, 7*(1), 37-46. doi:https://doi.org/10.1002/dys.185

Snowling, M., & Hulme, C. (1994). The Development of Phonological Skills. Philosophical Transactions: Biological Sciences, 346(1315), 21-27. Retrieved April 13, 2021, from http://www.jstor.org/stable/56015

Spratford, M., Walker, E. A., & McCreery, R. W. (2019). Use of an application to verify classroom acoustic recommendations for children who are hard of hearing in a general education setting. *American journal of audiology*, 28(4), 927-934.

Stanovich, K.E. (1988). Explaining the differences between the dyslexic and the garden-variety poor reader: The phonological-core variable-difference model. *Journal of learning disabilities*, 21(10), 590-604.

Stanovich, K. E., & Siegel, L. S. (1994). Phenotypic performance profile of children with reading disabilities: A regression-based test of the phonological-core variable-difference model. *Journal of educational psychology*, *86*(1), 24.

Stein, J. (2001). The magnocellular theory of developmental dyslexia. *Dyslexia*, *7*(1), 12-36. doi: 10.1002/dys.186

Stein, J., & Walsh, V. (1997). To see but not to read; the magnocellular theory of dyslexia. *Trends in neurosciences*, *20*(4), 147-152.

Swan, D., & Goswami, U. (1997). Phonological awareness deficits in developmental dyslexia and the phonological representations hypothesis. *Journal of experimental child psychology*, 66(1), 18-41. doi: 10.1006/jecp.1997.2375

Tallal, P. (1984). Temporal or phonetic processing deficit in dyslexia? That is the question. *Applied Psycholinguistics*, *5*(2), 167-169. doi: 10.1017/s0142716400004963

Thompson, P.A., Hulme, C., Nash, H.M., Gooch, D., Hayiou-Thomas, E., & Snowling, M. J. (2015). Developmental dyslexia: predicting individual risk. *Journal of Child Psychology and Psychiatry*, *56*(9), 976-987.

Torgesen, J.K., Wagner, R.K., & Rashotte, C.A. (2012). *Test of Word Reading Efficiency- 2nd ed. (TOWRE-2)* Austin, TX: Pro-Ed.

Treiman, R. (1992). The role of intrasyllabic units in learning to read and spell. *Reading Acquisition*, 65-106. doi:10.4324/9781351236904-4

Treiman, R., & Zukowski, A. (1991). Levels of phonological awareness. Phonological processes in literacy: A tribute to Isabelle Y. Liberman, 67-83.

Van der Kruk, Y., Wilson, WJ, Downing, C., Palghat, K., Harper-Hill, K., & Ashburner, J. (2017). Improved signal-to-noise ratio and classroom performance in children with Autism Spectrum Disorder: A systematic review. *Review Journal of Autism and Developmental Disorders , 4(3),* 243–253. doi: 10.1007/s40489-017-0111-7.

Vannest, K. J., & Ninci, J. (2015). Evaluating intervention effects in single-case research designs. Journal of Counseling & Development, 93(4), 403-411.

Vellutino, F. R. (1979). Dyslexia: Theory and research.

Vellutino, F. R., Fletcher, J. M., Snowling, M. J., & Scanlon, D. M. (2004). Specific reading disability (dyslexia): What have we learned in the past four decades?. *Journal of child psychology and psychiatry*, *45*(1), 2-40.

Vellutino, F. R., Scanlon, D. M., Sipay, E. R., Small, S. G., Pratt, A., Chen, R., & Denckla, M. B. (1996). Cognitive profiles of difficult-to-remediate and readily remediated poor readers: Early intervention as a vehicle for distinguishing between cognitive and experiential deficits as basic causes of specific reading disability. Journal of Educational Psychology, 88(4), 601.

Wales, D., Skinner, L., & Hayman, M. (2017). The efficacy of telehealth-delivered speech and language intervention for primary school-age children: a systematic review. International Journal of Telerehabilitation, 9(1), 55.

Wagner, R. K., & Torgesen, J. K. (1987). The nature of phonological processing and its causal role in the acquisition of reading skills. *Psychological bulletin*, *101*(2), 192. doi: 10.1037/0033-2909.101.2.192

Wagner, R.K., Torgesen, J.K. Rashotte, C.A., & Pearson, N.A. (2013). *Comprehensive Test of Phonological Processing-2nd ed. (CTOPP-2).* Austin, TX: Pro-Ed.

Wagner, R. K., Zirps, F. A., Edwards, A. A., Wood, S. G., Joyner, R. E., Becker, B. J., . . . Beal, B. (2020). The prevalence of dyslexia: a new approach to its estimation. *Journal of Learning Disabilities, 53*(5), 354-365.

Waite, M. C., Theodoros, D. G., Russell, T. G., & Cahill, L. M. (2010). Assessment of children's literacy via an internet-based telehealth system. *Telemedicine and e-Health*, *16*(5), 564-575.

Werfel, K.L., Grey, B., Johnson, M., Brooks, M., Cooper, E., Reynolds, G., Deutchki, L., Vachio, M., & Lund, E.A. (in press). Transitioning speech-language assessment to a virtual environment: Lessons learned from the ELLA study. Language, Speech and Hearing Services in Schools.

Werfel, K.L., & Hendricks, A. (2016). Identifying minimal hearing loss and managing its effects on literacy learning. *Teaching Exceptional Children*.

Werfel, K. L., Peek, L., Reynolds, G., & Bassard, S. (2020). Hearing screen failure among students with reading impairment: Rate and relation to specific reading deficits. SIG 9 Perspectives of the ASHA Special Interest Groups. doi: 10.1044/2020_PERSP-19-00163

Werfel, K.L., & Reynolds, G. (2019). Teaching phonological awareness to children with hearing loss who use spoken language: Six big ideas. SIG 9 Perspectives of the ASHA Special Interest Groups, 4(5), 954-961. doi: 10.1044/2019_PERS-SIG9-2019-0002

Werfel, K. L., & Schuele, C. M. (2012). Segmentation and representation of consonant blends in kindergarten children's spellings. *Language, Speech, and Hearing Services in Schools*. doi:10.1044/0161-1461(2012/11-0005)

Werfel, K.L., & Schuele, C. M. (2014). Improving initial sound segmentation skills of preschool children with severe to profound hearing loss: An exploratory investigation. *The Volta Review*, *114*(2), 113-134. doi: 10.17955/tvr.114.2.737

Williams, J. P. (1980). Teaching decoding with an emphasis on phoneme analysis and phoneme blending. *Journal of Educational Psychology, 72*(1), 1–15. https://doi.org/10.1037/0022-0663.72.1.1

White-Schwoch, T., Carr, K., Thompson, E., Anderson, S., Nicol, T., Bradlow, A., & Kraus, N. (2015). Auditory processing in noise: A preschool biomarker for literacy. *PLoS Biology,13*(7), e1002196. doi:10.1371/journal.pbio.1002196

Ziegler, J., Pech-Georgel, C., George, F., & Lorenzi, C. (2009). Speech-perception-in-noise deficits in dyslexia. *Developmental Science, 12*, 732-745. doi: 10.1111/j.1467-7687.2009.00817.x

Ziegler, J. C., Pech-Georgel, C., George, F., Alario, F. X., & Lorenzi, C. (2005). Deficits in speech perception predict language learning impairment. *Proceedings of the National Academy of Sciences*, *102*(39), 14110-14115. doi: 10.1073/pnas.0504446102

Zoccolotti, P., De Luca, M., Marinelli, C. V., & Spinelli, D. (2014). Modeling individual differences in text reading fluency: a different pattern of predictors for typically developing and dyslexic readers. *Frontiers in Psychology, 5*(1374). doi:10.3389/fpsyg.2014.01374

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APPENDIX A

BASELINE SCORES FOR DISCONTINUED STUDY 1

PARTICIPANTS

Participant 5

	Segmenting	Isolation	Deletion
Baseline day 1	8	10	2
Baseline day 2	10	7	0
Baseline day 3	10	6	1

Participant 6

	Segmenting	Isolation	Deletion
Baseline day 1	10	8	2
Baseline day 2	9	3	3
Baseline day 3	8	5	1

Participant 7

	Segmenting	Isolation	Deletion
Baseline day 1	6	8	4
Baseline day 2	6	5	3
Baseline day 3	8	10	5
Baseline day 4	8	9	4
Baseline day 5	10	10	4

APPENDIX B

PROGRESS MONITORING ASSESSMENT

Assessment Date:

Child Code:

Shuffle the deck of assessment cards.

Segmenting*: We're going to be breaking words up into their sounds. Let's do an example. Say the word "cat". Now, tell me all the sounds in the word "cat". That's right c-a-t are the sounds in the word cat.* If the child tells you letters, say, *those are the letters of the word but can you tell me the sounds. Listen carefully because I can only say the words once.* If the child is unable to perform this task, tell them the correct answer for this word but do not provide another example word. Allow 5 seconds to respond.

Segmenting
1.
2.
3.
4.
5.
6.
7.
8.
9.
10.

Blend Deletion*: We're going to be changing some sounds in words. Let's do an example. Say the word "sun". Now, say "sun" without the "s" sound. That's right, sun without the "s" sound is "un". Listen carefully because I can only say the words once.* If the child is unable to perform this task, tell them the correct answer for this word but do not provide another example word.

Blend Deletion- First Sound	Blend Deletion- Second Sound
1.	6.
2.	7.
3.	8.
4	9.
5.	10.

Isolation: *I'm going to be asking you about where some sounds are in words. Let's do an example. Say the word "pan". What is the first sound in the word "pan". That's right, the first sound in the word "pan" is "p".* If the child tells you letters, say, *those are the letters of the word but can you tell me the sounds. Listen carefully, because I can only say the words once.* If the child is unable to perform this task, tell them the correct answer for this word but do not provide another example word.

Isolation- Second Sound	Isolation- Second Sound
1.	6.
2.	7.
3.	8.
4	9.
5.	10.

APPENDIX C

PROGRESS MONITORING ASSESSMENT MASTER WORD LIST

/l/ blends	**/r/ blends**	**/s/ blends**
plum	price	swim
plane	prize	sweet
pluck	press	slide
plan	proof	snack
plaid	prop	snake
plop	pride	stick
block	broom	stop
bloom	brown	sneeze
blues	bread	stoop
blare	break	stock
blush	brook	snooze
bliss	bribe	scab
clap	crop	skied
cloud	crown	still
clock	crib	skill
cluck	crate	scan
clash	cream	star
clam	creep	sweat
glass	green	stem
globe	grape	swing
glove	grass	sweep
glued	grip	slip
glug	grin	spot
glad	grab	slime
flag	fruit	spook
floor	frog	space
flame	freed	spin
flush	frock	skin
flesh	freak	scoop
flip	fries	speck

APPENDIX D

STUDY 1 PROCEDURAL FIDELITY CHECKLIST

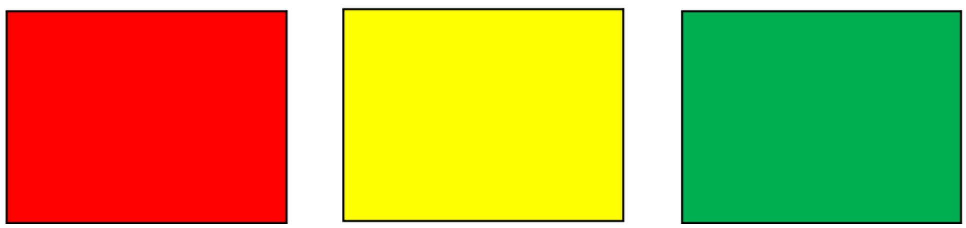
Observer:
Teacher:
Date:

Procedural Fidelity Checklist

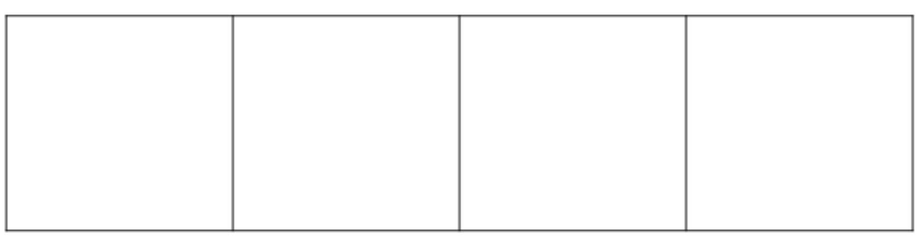
Yes	No	
□	□	Examiner has materials specified in lesson plan.
□	□	Examiner gives directions for activity as written in lesson plan.
□	□	Examiner executes lesson activities as written in lesson plan.
□	□	Examiner targets the correct sound.
□	□	Each lesson lasts duration of time written in lesson plan.
□	□	Examiner is able to equip student with FM system in under 5 minutes.
□	□	Examiner provides feedback consistently across students.

APPENDIX E

EXAMPLE IMAGES FROM VIRTUAL INTERVENTION



Colored square boxes for segmenting and isolation activities



Blend “sound box” activity PowerPoint slide

“Sound puzzle” boxes activity

APPENDIX F

STUDY 2 PROCEDURAL FIDELITY CHECKLIST

Observer:

Date:

Yes No

□ □ Interventionist has materials specified in lesson plan.

□ □ Interventionist checks sound levels using Decibel X app.

□ □ Interventionist gives directions for activity as written in lesson plan.

□ □ Interventionist executes lesson activities as written in lesson plan.

□ □ Interventionist targets the correct sounds.

□ □ The session is split evenly between lessons.

□ □ The child's face is visible on the computer screen.

□ □ Interventionist provides feedback consistently across activities.